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Application of Six Sigma for Process Improvement at an Engineered Medical Components Company

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Application of Six Sigma for Process Improvement at an

Engineered Medical Components Company

by

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Abstract

The project demonstrates the empirical application of Six Sigma and DMAIC to reduce product variation and yield loss within an engineered medical components company. This study followed the DMAIC methodology to investigate root causes and provided solution to reduce these defects. The analysis indicated the current sensitivity setting for the machine was set to tight. After adjustment, while machine kept the same production capacity, the yield loss was reduced from 10% to 2%. Meanwhile, a DOE study analyzed factors which caused product variation and delivered optima setting to reduce noises and predicted the optima output.

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Chapter I: Introduction

Introduction

This capstone project report focuses on the successful implementation of Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) methodology in an engineered medical components company. This project was focused on two problems round a wire ablation machine in the company. The two problem were product variation and product yield loss. A series of tools and strategies were being used during this project in order to achieve the objectives such as Paired T test, design of experiments (DOE) with Taguchi methods, Capability Analysis, etc. Additionally, graphical analyzes also utilized to provide Intuitive result for made meaningful inferences or conclusions. Such as fishbone diagram, box plot, and control chart. This report step by step described the process of this project start from project design, data collect, data analyze, and process improved. All data collected during this study is listed in this report. At the end, the results confirmed the six sigma methodology were applied successfully and it has been presented in the last chapter of this report.

Problem Statement

During production of the part on wire ablation machine W08, the company was scrapping approximately 10% of products due to the automated inspection systems detecting outside diameter discrepancies on the proximal and distal ablation area.

During in-process inspection, the company was seeing a large range in the measurement for the proximal ablation length which is causing the client to perform additional inspection due to incoming Ppk values being less than 1.0.

Nature and Significance of the Problem

In today's fast-paced global economy, markets demand that companies produce their products more quickly with better quality and at the same time with lesser cost. It required companies adopt various methodologies for process improvement. Recently, the company wanted to adopt Six Sigma for process improvement. Accumulate experiences is very important for a new Six Sigma project team. Therefore, the manager and engineer team decided to focus on one current running machine as a start of conduct Six Sigma project. As introduced in previous section, the selected machine is the newest model of machine purchased in the company. The producing products by this machine have an undesirable level of yield loss need to be improved. In Six Sigma, DMAIC is commonly used for making improvements in existing processes. This approach not only makes use of Six Sigma tools and techniques, it also incorporates other concepts such as financial analysis and project management. Therefore, this project first will be using for yield improvement, and then the result will to be archived processes improvement around company.

Objective of the Project

The objectives of the project were divided into two sections:

- At the project level, the goal was to increase first pass yield from 90% to 95% or higher for residue/debris.
- At the corporate level, the goal was improving customer satisfaction by raising Ppk values, for all variable dimensions above 1.0 at the Customer's Incoming Quality Control (IQC).

Project Questions

The following questing were answered at the end of this study:

- What was the current state for the process at wire machine W08?
- What factors caused the yield loss?
- What changes should be made to the process for improvement?
- What percentage of yield loss was reduced after the study was conducted?

Limitations of the Project

The process would have more space to be improved due to the limitation of resources. Such as time, labor, budget. Some analysis and experiments have been done during downtime of the process which was limited. Also, the operators, QA, and Six Sigma team members may not available when project needed. The wire ablation machine is expensive, any changes of it, parts or program would cost a lot. Therefore, the experiments and improved were based on reasonable adjustment.

Definition of Terms

Yield loss. The difference between the actual yield of a product and the yield theoretically possible of a product with the same properties.

Design of experiments (DOE). A statistics-based approach for exploring multifactor opportunity spaces, to properly uncover how factors jointly affect the response. It is to achieve a predictive knowledge of a complex, multi-variable process with the least trials possible. It is an optimization of the experimental process itself.

Taguchi method. A kind of low cost, high benefit of quality engineering methods, it emphasizes that the improvement of product quality is not through the inspection, but by design. The basic idea is to put the product robust design to product and manufacturing process, by controlling the quality of source to withstand a lot of noise in customer using or uncontrollable factors.

Standard deviation. The standard deviation measures the variability of the given data. If the standard deviation is low, it indicates that the values are closer to the mean. If the standard deviation is high, it indicates that the values are spread out.

Process capability. It determines how good the measurements are when compared to the specification limits. The process capability can be assessed by means of histograms and capability indices. The capability indices are the ratios of specification tolerance to the natural process variation.

Summary

In the first chapter, it states the problems and the objectives of this project. It also comes with few questions which will be answered thought this report. The background round this problem will be presented in next chapter.

Chapter II: Background and Review of Literature

Introduction

In this chapter, background round this problem will be presented along with literature reviews.

Background Related to the Problem

Engineered medical components company (the Company) partners with medical device manufacturers to design and manufacture state-of-the-art technology solutions for virtually every clinical application. It involves in varied precision components during design and manufacturing process which requires continuous and systematic innovation to remain cost effective, efficient and provide high quality product s and services.

This study was focusing on a several of process improvement on a latest purchased laser ablation machine through Six Sigma to achieve eliminating defects at the project level and improving performance and customer satisfaction at the corporate level.

Wire ablation machine W08 is a set of tools on workstation to perform Automatic laser ablation on ultrafine wire with inspection. The machine will strip the wire for the distal ablated area; pull the wire a short distance and take a picture of the distal ablation. Then the wire will continue to be pulled to the right to start creating the proximal strip, when proximal strip is complete it will be pulled through a micrometer and outside diameter (O. D.) will be measured for possibility of insulation. Wire will then be pulled to the end of trough and dropped.

The most critical standards for both the company and the customer were proximal ablation outside diameter, proximal ablation length and the length between distal and proximal ablation which called insulation length. The ablation outside diameter failed to inline inspection was the most reason the operators scrap the parts. There was a similar wire ablation machine but old model producing the same parts. However, it was produced the parts for years with around 99% yield and never receive complain by customer. The W08 wire ablation machine has a better computer controlled and monitoring system. It can perform more accurate and fine ablation on wire which would be the next tab of part the company plan to produce. The old machine cannot produce this new tab of part. W08 wire ablation machine and the old wire ablation machine were used the raw material from same lot and the final products were the same. They performed a similar process which only difference is W08 has additional inline inspections. Therefore, the engineer team thought the W08 wire ablation machine was actually failed good parts during the inline inspection. The current sensitivity setting for the laser micrometer system was 1X12 Microns. This means that the system will fail a part that has particles 1 Micron high by 12 Microns long within the proximal ablation. The Products were validated at a Keyence laser micrometer sensitivity setting of 3X25 Microns. The sensitivity was increased during trial runs of other products due to issues with redeposition of ablated material. (These issues have been greatly reduced.) The goal was to ensure a clean ablation. These settings carried through to production runs of the Products. Then the proximal ablation length and the insulation length were having issue with. They are both measured by operators manually in a measure station.

Literature Related to the Problem

Many organizations have pursued formalized change programs or quality initiatives. Such as Six Sigma, become a popular methods and strategies to have significant impact on the bottom line and working culture for those organizations (Gijo & Scaria, 2014). Managers in the engineered medical components company search for administrative innovations that can potentially improve their business processes and enhance operating performance. In the early step of adopt Six Sigma with limit experiences, a basic approach and DMAIC as the key structure and methodology for bring change to the company. According to Kumaravadivel and Natarajan (2013), Atkinson (2014), and Gijo and Scaria (2014), the DMAIC is a very power methodologies which can be applied in large organizations. The Six Sigma DMAIC methodology achieves reduction of wastage through rejects and improves the quality of the output in the process by working on the technical factor as well as the human factor involved in the process (Kumaravadivel & Natarajan, 2013).

Literature Related to the Methodology

Before conduct a project, an important thing need to consider first. Engineering decisions must consider money, both in the short term and in the long term. Otherwise, the project is meaningless to company. The decisions must balance economics, performance, esthetics, resources, etc. (Eschenbach 1995). Solution is to apply engineering economy as part of a well-structured decision making process.

Engineering economy evaluates the monetary consequences of the products, projects, and processes that engineers design. There products, projects, and processes usually require spending money now, and they have long lives. The process of decision making are follow the steps as the flowchart: define problem, choose objective, identify alternatives, evaluate consequences, select, implement, audit. Though useful literatures, this project have been defined and move to next phase which actually application Six Sigma DMAIC methodology.

DMAIC is commonly used for making improvements in existing processes (Gijo & Scaria, 2014). Many of case study proof of the successful implementation of Six Sigma DMAIC methodology approach resulted in reduction of process problems and elimination of product defects. In today’s marketplace, the focus of improvement has moved from traditional Lean Six Sigma to the application of the behavioral sciences (Atkinson, 2014).

By review of successful case studies of application of six sigma DMAIC methodology for process improvement, many of tools and strategies have common focus which can be easy understand and apply to other process. The five phases of DMAIC are Define, Measure, Analyze, Improve, and Control, than the five phases can be divided into two stages, process characterization and process optimization. During DMAIC methodology have been processing, as many as tools should be using when it applicable. Pictures and graphs are often worth than thousand words (Atkinson, 2014). Therefore, Such as process mapping, histograms, and box plot, would be important for this study. According to the successful case studies by

Kumaravadivel and Natarajan (2013) and Gijo and Scaria (2014), the tools and strategies have selected for this study in order to gain the understanding of conduct Six Sigma of processes in engineered medical components company.

There are a variety of models, methods and tools aimed at helping organizations in reduce defects during application DMAIC methodology (Lazic & Milinkovic, 2015). In this study, the team suggested a strategy for the optimization of the action plans in the test process by applying the design of experiments to the testing of machine's setting. This was accomplished by the application of Taguchi's design of experiments and analysis of variance (ANOVA) methodology in order to find the optima setting to obtain the optima output. The science of statistical experimental design originated with the work of Sir Ronald Fisher in England in the 1920s.And the analysis of variance was founded by Fisher for the basic principles of experimental design and the associated data analysis technique. According to the Phadke's Quality engineering using robust design (1989), this two methodology have been well defined and step by step instructed. The estimated effects of design parameters must be valid even when other parameters are changed during the subsequent design effort or when designs of related subsystem change. This can be achieved by employing the signal to noise (S/N) ratio to measure quality and orthogonal arrays to study many design parameters simultaneously.

A process is a unique combination of tools, materials, methods, and people engaged in producing a measurable output; for example a manufacturing line for machine parts. All processes have inherent statistical variability which can be evaluated by statistical methods. The Process Capability is a measurable property of a process to the specification, expressed as a process capability index (e.g., Cp or Cpk) or as a process performance index (e.g., Pp or Ppk). The output of this measurement is usually illustrated by a histogram and calculations that predict how many parts will be produced out of specification (OOS). The process capability refers to the uniformity or consistency of the process. Obviously, the variability of critical to quality characteristics in the process is a measure of the uniformity of the output. There are two ways to think of variability: The natural or inherent variability in a CTQ at a specified time. And the variability in a critical to quality characteristics over time. Process capability indices (PCIs) are extensively used to determine whether a process is capable of producing objects within customer specification limits or not. Process capability indices are useful tools for evaluating the ability of a process to produce the dependent variables of a product that meet certain specifications. Process capability indices are useful tools for evaluating the ability of a process to produce the dependent variables of a product that meet certain specifications. Khodaygan and Movahhedy (2014) described process capability analysis in mechanical systems in their research paper. They extended the conventional process capability concept to a computational tool for analysis of the functional quality of a mechanical product.

Box plots are also a frequently used tool. Lem, Onghena, Verschaffel, and Van Dooren (2013) heuristic interpret the box plot. In descriptive statistics, a box plot or box plot is a convenient way of graphically depicting groups of numerical data through their quartiles. Box plots may also have lines extending vertically from the boxes (whiskers) indicating variability outside the upper and lower quartiles, hence the terms box-and-whisker plot and box-and-whisker diagram. Outliers are plotted as individual points with a symbol appearing as per the magnitude away from the box and whiskers. The box plot usually depicts the 5-point summary namely; the minimum, first quartile (Q_1), Median (Q_2), third quartile (Q_3) and the maximum along with outliers if any present in the data set.

After World War Ⅱ, Japan has begun its reconstruction efforts. It faced a shortage of good quality of raw material, high quality of manufacturing equipment and skilled engineers. The challenge was to produce high quality products and continue to improve the quality under those circumstances. Through 1950s Dr. Genichi Taguchi was assigned the task of developing a methodology to meet the challenge. In the early 1960s, Dr. Taguchi developed the foundations of Robust Design and validated its basic philosophies by applying them in the development of many products.

The Robust Design method can be applied to a wide variety of problems. The application of the method in electronics, automotive products, photography and many other industries has been an important factor in the rapid industrial growth and the subsequent domination of international markets in these industries by Japan (Phadke, 1989).

The design of experiments and analysis of variance were the biggest part in this study. A series of tools and strategies from Phadke (1989) were considered used for achieve the objectives. A matrix experiment consists of a set of experiments that change settings of the various product or process parameters to study from one experiment to another. After conducting a matrix experiment, the data from all experiments in the set taken together are analyzed to determine the effects of the various parameters. Conducting matrix experiments using special matrices, called orthogonal arrays. The orthogonal arrays is an important technique in Six Sigma and Robust Design. The number of independent parameters associated with an entity like a matrix experiment, of a factor, or a sum of squares is called its degrees of freedom. A matrix experiment with nine rows has nine degrees of freedom and so does the grand total sum of squares. The overall mean has one degree of freedom and so does the sum of squares due to mean. Thus, the degrees of freedom associated with the total sum of squares is nine minus one equal to eight.

Different factors affect the surface defect formation to a different degree. The relative magnitude of the factor effects could be judged gives the average η for each factor level. A better feel for the relative effect of the different factors can be obtained by the decomposition of variance, which is commonly called analysis of variance. Analysis of variance is also needed for estimating the error variance for the factor effects and variance of the prediction error.

Summary

This chapter described the background and literature reviews related to this project. In next chapter, will start to describe how this study has been designed and how data has been collected.

Chapter III: Methodology

Introduction

In this chapter, the detail of how was the study has been designed will be explained. Then the chapter will step by step show the process of the data collection plan, and how those data would be analyzed by used what tool or technique.

Design of the Study

This study was developed by the researcher while working with the organization to provide support for the project in Six Sigma methodology. The Define, Measure, Analysis, Improve and Control (DMAIC) method was used to achieve the objectives of this study. The data was collected from the process based on a data collection plan and estimated the baseline performance of the process. Based on this information, a project charter and a process map were created at the Define phase which is the first phase of DMAIC methodology. The objective of the measure phase in this six sigma study was to evaluate the baseline performance of the process in several ways such as conducting Gage R&R to evaluate the manual measure by different operators.

Data Collection

The data collection is divided to several sections based on the step of conduct the six sigma project by used DMAIC methodology.

Baseline performance. Before this study can help the process to improve, the baseline performance should be understood. As mentioned in previous, a process map was created to gain the better understanding of the whole process. The

Company is using Infinity QS software to collect and analyze data during production and provide it to customers. Discussed separately for the wire ablation machine W08, the distal ablation OD and length data along with proximal ablation OD are stored into Infinity OS immediately after inline inspection automatically. Due to the reading variation of the proximal ablation length for two Keyence laser micro cameras, the inspection for the proximal ablation length and insulation length are measured offline manually by operators. The manual measurement follow the c=0 sampling plan associated with 1.0 AQLS.

Yield loss. First, the data was been collected was the defect record for recent completed lot which came from Infinity OS database. Then compare the proximal inspection data at the current Keyence sensitivity settings to two reduced settings that are still within the validated parameters. All failed data from the recent completed lot was analyzed to see if it would still fail at settings of 2X12 Microns and 3X12 Microns. The next step was to run a representative sample at each of the reduced settings to ensure the expected yield is obtained. Random samples (both passing and failing) were taken for analysis to verify the risk is low enough. The standard production settings for the proximal inspection system would be adjusted to either 2X12 Microns or 3X12 Microns.

Root cause. Furthermore, a brainstorming meeting was hold by the team with others who involved with the process of wire ablation in wire ablation machine W08 to analyze the root causes for variation of proximal ablation length. A fishbone diagram was created during the meeting which will present in next chapter.

Uncoordinated measure system. Before conduct DOE or other study related to proximal ablation length, need to coordinate the measure systems. Because of the measurements for proximal ablation was doubtful for inspection compare with the two readings from two Keyence laser micro cameras and manual measurement.

Design of experiments. After the inline measuring system has been coordinated, the DOE could be started. A team meeting was holding for design the experiments. 8 main effects and their different levels have been estimated as factors and levels in this study. 1 factor has 2 level and 7 factors have 3 level. The factors were based on the result from root cause analysis, the level were based on the current setting and the setting range which would still perform good parts. The factors and levels list in Table 1.

Table 1: Factors and Levels for DOE

Factor	Stabilizer Oscillation	Carriage Acceleration	Carriage Velocity	Carriage Deceleration	Carriage Jaw Pressure	Collet Jaw Pressure	Payout Torque	Payout Angular Velocity
low setting	ON	10	150	250	35	30	75%	50
normal setting		250	500	500	50	60	200%	205
high setting	OFF	1750	2500	2500	90	80	400%	700

The factor of stabilizer oscillation just need consider if it is on or off, so only 2 levels. The factors of carriage acceleration, velocity and deceleration are only limit options which were set by technician from the manufacturer of the machine. Any additional profile need require to the manufacturer programming into machine which would cost a lot. Therefore, before go to require more profiles, the study only picked three existing setting for each factor which are showed on Table 1. For factors like Jaw Pressure or payout setting, although could arbitrary select from a wild range it would damage or slip the wire during production process. Therefore, the setting on Table 1 would be already used all of range from lowest to highest which the machine still able to producing good parts.

After the factors and levels have been estimated, it needs to calculate the degree of freedom and choose appropriate orthogonal array. Which would be:
1 x (2 – 1) + 7 x (3 – 1) + 1 = 1 + 14 + 1 = 16. By checked from the Taguchi tabulated 18 basic orthogonal arrays shows on Table 2, L18 orthogonal array is the best choice for the experiment which detailed list in Table 3.

Table 2: Taguchi Tabulated 18 Basic Orthogonal Arrays

Orthogonal Array*	Number of Rows	Maximum Number of Factors	Maximum Number of Columns at These Levels			
			2	3	4	5
L_4	4	3	3	–	–	–
L_8	8	7	7	–	–	–
L_9	9	4	–	4	–	–
L_{12}	12	11	11	–	–	–
L_{16}	16	15	15	–	–	–
L'_{16}	16	5	–	–	5	–
L_{18}	18	8	1	7	–	–
L_{25}	25	6	–	–	–	6
L_{27}	27	13	–	13	–	–
L_{32}	32	31	31	–	–	–
L'_{32}	32	10	1	–	9	–
L_{36}	36	23	11	12	–	–
L'_{36}	36	16	3	13	–	–
L_{50}	50	12	1	–	–	11
L_{54}	54	26	1	25	–	–
L_{64}	64	63	63	–	–	–
L'_{64}	64	21	–	–	21	–
L_{81}	81	40	–	40	–	–

* 2-level arrays: L_4, L_8, L_{12}, L_{16}, L_{32}, L_{64}.
3-level arrays: L_9, L_{27}, L_{81}.
Mixed 2- and 3-level arrays: L_{18}, L_{36}, L'_{36}, L_{54}.

Table 3: L18 Orthogonal Array

$L_{18}\ (2^1 \times 3^7)$

$L_{18}\ (2^1 \times 3^7)$ Orthogonal Array

Expt. No.	Column 1	2	3	4	5	6	7	8
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

The next step was adjusted factor settings coincidence to each experiment of L18 orthogonal array and running the machine. The inline measurement reading from laser micro camera 1 for each part has been recorded and also with the reading from laser micro camera 2 as reference. There were 5 yields for each different setting. So there would be total 90 pair of data have been recorded and been used for analysis.

Data Analysis

This section will list and describe the tools and statistical techniques that were used to analyze data for this study. The data collected during this study were analyzed by using various statistical techniques. Such as Paired T test, design of experiments (DOE) with Taguchi methods, Capability Analysis, etc. Additionally, Graphical analyzes also utilized to provide Intuitive result for made meaningful inferences or conclusions. Such as fishbone diagram, box plot, and control chart.

In detail, the Control chart and Pareto chart were used to shows the performance baseline. There are created by used Infinity OS. A Fishbone diagram was created to identify the root causes of the proximal ablation length variation. The Paired T test, probability plot, and box plot were used to compare two laser micro cameras reading to coordinate the inline measure system with manual measurement. In the DOE part, all data analyzed through Minitab. First, the data was analyzed with Taguchi methods. Then conduct the ANOVA analysis along with Interaction Plot and Contour plot. At the end, predicted the output at optima setting by Minitab and verification the results. .

Budget

This project involved with some types of cost which are itemized below on Table 4.

Table 4: The Project Costs

Cost Type	Vendor / Labor Names	Rate	Qty	Amount
Machine	W08	$78.00/Hour	96	$7,488
Labor	Operator	$24.00/Hour	48	$1,152
Labor	QA	$24.00Hour	6	$144
Material	Wire	$780.00/spool	4	$3,120
Maintenance	Additional Programming	$180.00/Hour	40	$4,320
			Total Costs	$16,224

The project costs were divided into four types. The first type was Machine, which included any cost involved during running W08 wire ablation machine. Such as power usage, room usage, gas usage, etc. The second type was labor, including needed for operators and QAs during this project. Then the third type of cost was material for production. 4 spools material have been purchased and used for this project. Each spool could produce about 700 parts. The last type of cost was maintenance. Most of this cost was for programming additional program by outsources to adjust the setting of W08 wire ablation machine. The total costs for the 4 type were $16224.

Timeline

Table 5: Project Timeline

Task Name	Duration	Start	Finish	Predecessors
Six Sigma Project	**75 days**	**Wed 6/10/15**	**Tue 9/22/15**	
Define Phase	**10 days**	**Wed 6/10/15**	**Tue 6/23/15**	
Project Charter	5 days	Wed 6/10/15	Tue 6/16/15	
Establish Resources	4 days	Wed 6/17/15	Mon 6/22/15	3
Kick-off Meeting	1 day	Tue 6/23/15	Tue 6/23/15	4
Measure Phase	**10 days**	**Tue 6/23/15**	**Tue 7/7/15**	**2**
Process Map	4 days	Wed 6/24/15	Mon 6/29/15	
Process Capability	5 days	Tue 6/30/15	Mon 7/6/15	7
Measure Phase Closing Meeting	1 day	Tue 7/7/15	Tue 7/7/15	8
Analyze Phase	**10 days**	**Tue 7/7/15**	**Tue 7/21/15**	**6**
Brainstorming Meeting	2 days	Wed 7/8/15	Thu 7/9/15	
Cause and Effect Diagram	7 days	Fri 7/10/15	Mon 7/20/15	11
Analyze Phase Closing Meeting	1 day	Tue 7/21/15	Tue 7/21/15	12
Improve Phase	**30 days**	**Tue 7/21/15**	**Tue 9/1/15**	**10**
System Sensitivity Study	10 days	Wed 7/22/15	Tue 8/4/15	
DOE	19 days	Wed 8/5/15	Mon 8/31/15	15
Improve Phase Closing Meeting	1 day	Tue 9/1/15	Tue 9/1/15	16
Control Phase	**10 days**	**Tue 9/1/15**	**Tue 9/15/15**	**14**
SPC (Infinity Monitoring)	4 days	Wed 9/2/15	Mon 9/7/15	
Work Instruction Updates	5 days	Tue 9/8/15	Mon 9/14/15	19
Control Phase Closing Meeting	1 day	Tue 9/15/15	Tue 9/15/15	20
Project Report	5 days	Wed 9/16/15	Tue 9/22/15	18

Summary

In this chapter, the data collect plan and analyze plan have been described. The actual data collected and the analysis results will be list on next chapter.

Chapter IV: Data Presentation and Analysis

Introduction

The actual data collected and the analysis results during this study will be presented in this chapter.

Data Presentation

In this section, the data was collected during this study will be presented by different categories as the data collection plan explained in previous chapter.

Performance baseline. Figure 1 is the X bar and R chart which was pulled from Infinity OS. It analyzed data for all samples' proximal ablation length from a complete lot production. The dimension of proximal ablation had the lowest Ppk value out of all dimensions for the part. From Figure 1, it clearly shows the lot only has a 0.96 of Ppk Value for total 60 samples. The 60 samples were First Piece Verification for every shift and material change, plus random picked during production by follow the c=0 sampling plan associated with 1.0 AQLS.

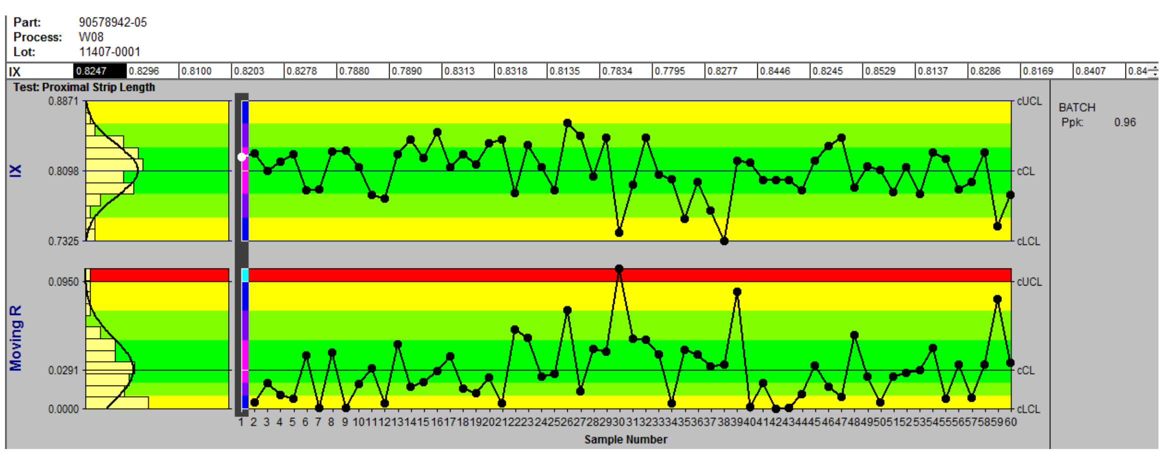


Figure 1: X Bar and R Chart

Based on the result, it required the company to improve the process performance in order to keep the customer satisfied.

Yield loss. Table 6 is the data export from Infinity OS, which is the defect record for recent completed lot. From this table, it shows the total parts have been produced for this lot is 7498, and the 92.83% yield loss caused by insulation residue. The insulation residue is detected by the two Keyence laser micro cameras during inline inspection for the OD of proximal ablation.

Table 6: Defect Code Pareto Chart

Category	Count	%Total	Pieces	%
029-Insulation Residue	660	92.83%	7498	8.80%
023-Handling Mark	23	3.23%	7498	0.31%
015-Ablated Length + Tolerance	14	1.97%	7498	0.19%
016-Ablated length - Tolerance	10	1.41%	7498	0.13%
040-Other	3	0.42%	7498	0.04%
041-Set-up/Technician Scrap	1	0.14%	7498	0.01%

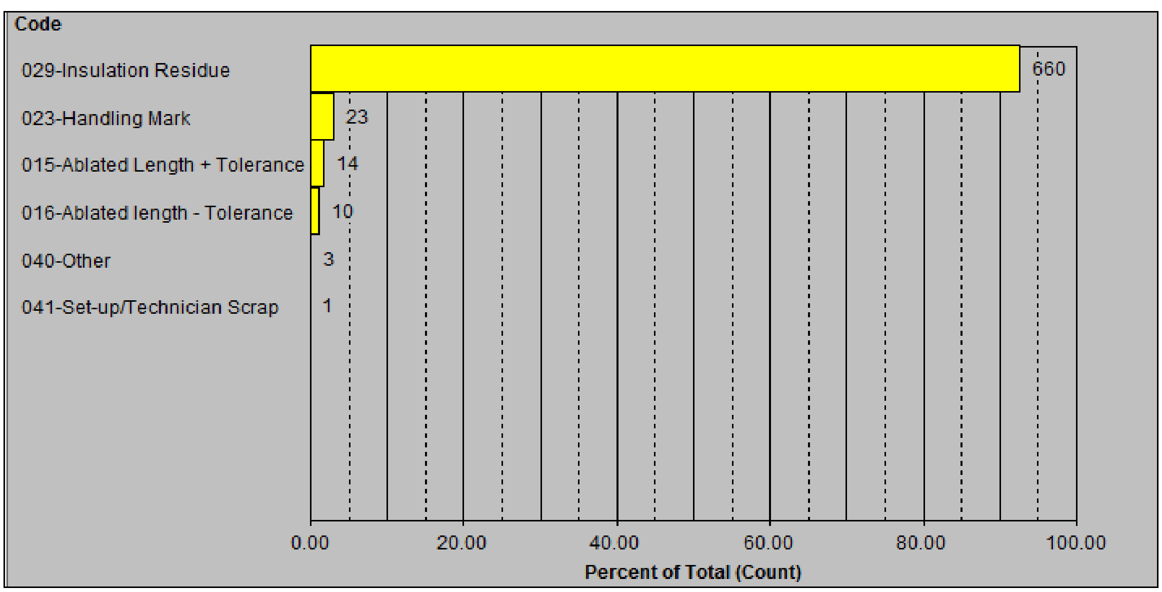


Figure 2: Defect Code Pareto Chart

After analyzed the proximal inspection data for the recent completed, there was 250 samples ran at each of the reduced settings to ensure the expected yield is obtained. The appendix, which is attached at the end of the report, is the pass/fail result for total sample ran for this Keyence sensitivity comparison.

Root cause analysis. Since the problem of length variation was more complicated, and it also critical to customer satisfaction. In order to find those root causes, the Six Sigma team held the brainstorming meeting and created the fishbone diagram which shows on below.

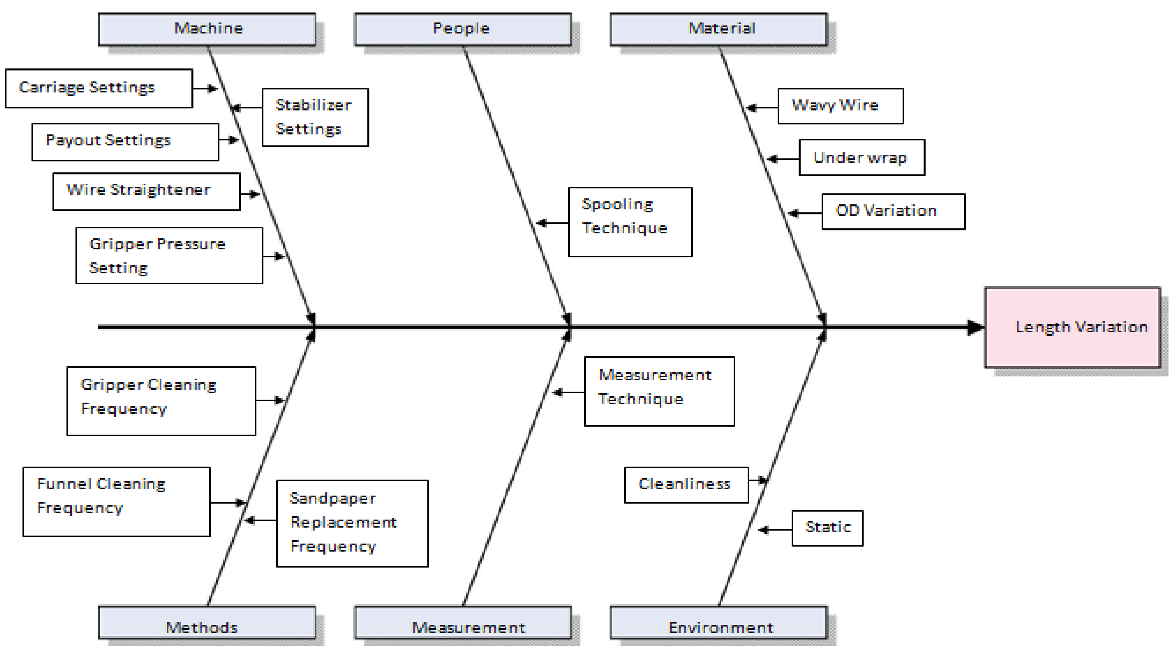


Figure 3: Fishbone Diagram

Uncoordinated measure system. In order to gain confidence on the measure system, a study was taken because of the variable measurements of proximal ablation length between two Keyence laser micro cameras and manual measurement. First, 30 parts samples have been taken and the results from two Keyence laser micro cameras and manual measure for proximal ablation length have been recorded and shows on Table 7.

Table 7: Result of Measure System Comparison Sample Trial

Part No.	laser micron 1 (mm)	laser micron 2 (mm)	Manual measurement (mm)
1	21.040	21.2660	20.3360
2	20.464	20.1210	19.7101
3	19.927	19.5030	19.9501
4	20.605	21.5020	21.3928
5	21.219	21.6670	20.7259
6	21.076	20.0650	20.0650
7	20.759	20.0220	20.0220
8	19.949	20.5749	20.5749
9	21.586	21.6237	21.7237
10	21.236	20.7649	20.7649
11	20.870	20.0770	20.0770
12	20.636	19.9311	19.9311
13	20.255	20.6479	20.6479
14	19.650	20.6759	20.6759
15	21.198	20.4849	20.4849
16	21.040	21.2660	20.3360
17	20.464	20.1210	19.7101
18	19.927	19.5030	19.9501
19	20.605	21.5020	21.3928
20	21.219	21.6670	20.7259
21	21.076	20.0650	20.0650
22	20.759	20.0220	20.0220
23	19.949	20.5749	20.5749
24	21.586	21.6237	21.7237
25	21.236	20.7649	20.7649
26	20.870	20.0770	20.0770
27	20.636	19.9311	19.9311
28	20.255	20.6479	20.6479
29	19.650	20.6759	20.6759
30	21.198	20.4849	20.4849

The data analysis of the 3 sets of measurement will be present in the next section.

Design of experiments. After follow L18 orthogonal array to conduct those experiments, there are total 90 pair of data have been recorded which list on below. Table 8 is the L18 orthogonal array with factors and levels, the experiments were conduct random order with 5 parts for each experiment. The Table 9 is the results from laser micro camera 1, Table 10 is the results from laser micro camera 2.

Table 8: L18 Orthogonal Array with Factors and Levels

No.	Stabilizer Oscillation	Carriage Acceleration	Carriage Velocity	Carriage Deceleration	Carriage Jaw Pressure	Collet Jaw Pressure	Payout Torque	Payout Angular Velocity
1	ON	10	150	250	35	30	75%	50
2	ON	10	500	500	50	60	200%	205
3	ON	10	2500	2500	90	80	400%	700
4	ON	250	150	250	50	60	400%	700
5	ON	250	500	500	90	80	75%	50
6	ON	250	2500	2500	35	30	200%	205
7	ON	1750	150	500	35	80	200%	700
8	ON	1750	500	2500	50	30	400%	50
9	ON	1750	2500	250	90	60	75%	205
10	OFF	10	150	2500	90	60	200%	50
11	OFF	10	500	250	35	80	400%	205
12	OFF	10	2500	500	50	30	75%	700
13	OFF	250	150	500	90	30	400%	205
14	OFF	250	500	2500	35	60	75%	700
15	OFF	250	2500	250	50	80	200%	50
16	OFF	1750	150	2500	50	80	75%	205
17	OFF	1750	500	250	90	30	200%	700
18	OFF	1750	2500	500	35	60	400%	50

Table 9: DOE Yields from Laser Micro Camera 1

No. of experiment	camera 1				
	yield 1	yield 2	yield 3	yield 4	yield 5
1	20.744	21.113	19.59	21.133	20.631
2	20.448	21.822	19.735	20.796	21.392
3	20.23	20.248	21.227	19.511	21.825
4	19.661	21.705	20.049	22.069	19.734
5	20.177	21.172	20.219	21.168	20.359
6	20.147	20.173	19.856	22.018	19.216
7	20.584	21.549	19.863	21.26	20.096
8	19.363	20.282	21.555	18.717	20.219
9	21.546	20.351	20.966	20.798	20.231
10	20.943	20.891	20.188	20.698	21.102
11	20.905	21.837	19.646	21.788	20.043
12	21.226	19.634	21.427	20.152	20.872
13	19.447	22.168	21.015	21.028	19.714
14	19.952	20.132	21.083	20.501	20.989
15	21.065	19.922	21.813	19.75	21.866
16	20.633	20.072	21.004	21.477	19.493
17	20.995	20.752	20.298	20.679	20.392
18	20.031	20.579	19.766	20.624	19.433

Table 10: DOE Yields from Laser Micro Camera 2

No. of experiment	camera 2				
	yield 1	yield 2	yield 3	yield 4	yield 5
1	21.799	20.581	19.76	22.46	19.193
2	21.468	21.316	19.306	22.287	21.058
3	20.997	19.319	23.047	18.406	22.542
4	19.822	22.942	19.426	22.954	18.686
5	19.018	21.907	18.903	21.957	19.319
6	21.436	20.812	19.112	22.307	18.625
7	21.536	21.202	19.676	22.079	19.009
8	19.429	18.254	22.211	18.817	19.77
9	21.897	20.699	19.464	21.817	19.613
10	22.309	22.046	19.559	21.537	20.214
11	20.244	23.537	19.053	21.892	20.138
12	21.926	19.405	22.902	18.999	21.554
13	18.233	22.86	19.986	22.386	18.308
14	19.588	21.196	20.547	19.334	21.638
15	22.261	19.106	22.666	19.826	22.643
16	18.893	20.089	22.13	21.132	18.596
17	21.94	19.032	21.2	19.863	20.458
18	18.513	22.216	18.419	22.196	18.04

After predicted by Minitab, there are 100 samples ran at optima setting to verify with the predicted result. Table 11 is the 20 random samples picked from the 100 samples and analyzed.

Table 11: DOE Samples at Optima Setting

Random Samples	
No.	yield
1	20.382
2	20.31
3	20.146
4	20.446
5	20.256
6	20.705
7	20.506
8	20.535
9	20.844
10	21.074
11	20.166
12	20.906
13	20.416
14	21.064
15	20.53
16	20.297
17	20.828
18	20.348
19	20.745
20	20.856

Data Analysis

Yield loss. The analysis procedure for the Keyence sensitivity comparison is follow as mentioned in data collection section. By compare the proximal inspection data at the current Keyence sensitivity settings to two reduced settings that are still within the validated parameters. The standard settings provided a yield of 90%. The same data set analyzed at a reduced height sensitivity of 1 Micron provided a yield of 96%. At a reduced height sensitivity of 2 Microns a yield of 98% was obtained. This would have been a 60% and an 80% reduction in defects respectively if these settings would have been used during the production of this lot. The next step was running a representative sample at each of the reduced settings to ensure the expected yield is obtained. 250 parts were processed at the standard Keyence sensitivity settings and other two lots, 250 parts each, were processed at reduced settings that are still within the validated parameters. Only the parts needed for off line measurement need to be spooled. Used C = 0 Sampling Plans associated AQL 1.0 which total took 20 samples for each lot for manual measurement. Few failed parts from each lot were taken pictures to see what the cause of fail was. The Table 12 is the pass/fail result for total sample ran for this Keyence sensitivity comparison.

Table 12: Result of Sample Trial Analysis

sensitivity	1x12		sensitivity	2x12		sensitivity	3x12	
trial number	status		trial number	status		trial number	status	
Total	250	100%	Total	250	100%	Total	250	100%
Green light	237	94.80%	Green light	247	98.80%	Green light	246	98.40%
Yellow light	10	4.00%	Yellow light	1	0.40%	Yellow light	0	0.00%
Red light	3	1.20%	Red light	2	0.80%	Red light	4	1.60%

Since the Keyence sensitivity comparison only focus on proximal ablation, so those red light were ignored and would not been affected by adjust the Keyence sensitivity. The data shows that, the lot at standard settings provided 94.8% of yield and 4% of parts failed proximal inspection. The lot at reduced height sensitivity of 1 Micron provided 98.8% of yield and 0.4% of parts failed proximal inspection. The lot at reduced height sensitivity of 2 Micron provided 98.4% of yield and 0% of parts failed proximal inspection.

By used 2500x zoom electron microscope, it shows as Figure 4 the parts failed inspections because of the raw materials have defect on the core wire. If the bubbles are insulation residue, the color of it should as the insulation skin which is golden but not like the metal core which is silver.

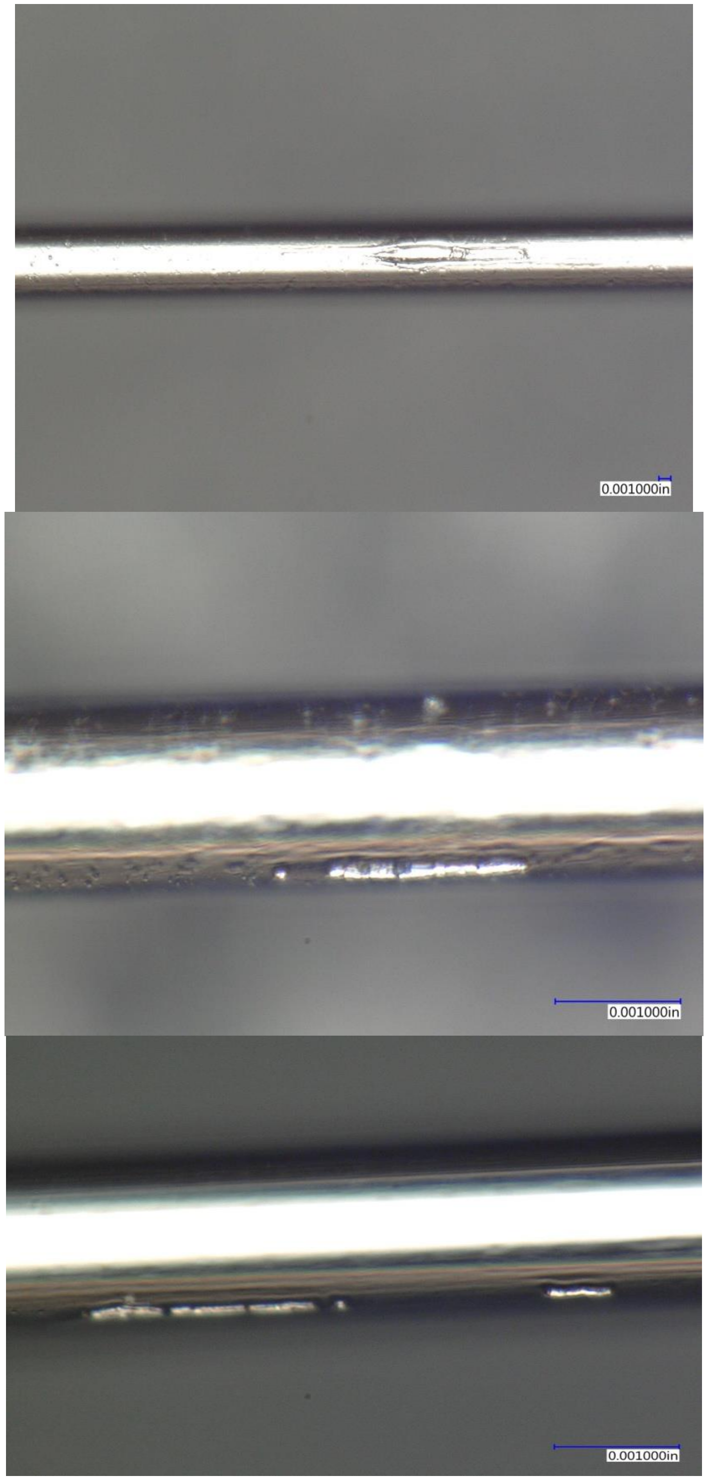


Figure 4: Failed Parts Under 2500x Electron Microscope

Uncoordinated measure system. Before compare the data to each other, it needs to use probability plot to see if the each set of data is normally distributed.

According to Figure 5, the standard deviation of laser micro camera 1 is 0.5104, is not that widely spread the values are around the mean. Then the Anderson-Darling value is 0.567 which lower than 0.75, the P Value is 0.129 which bigger than 0.05 means the data is normally distributed.

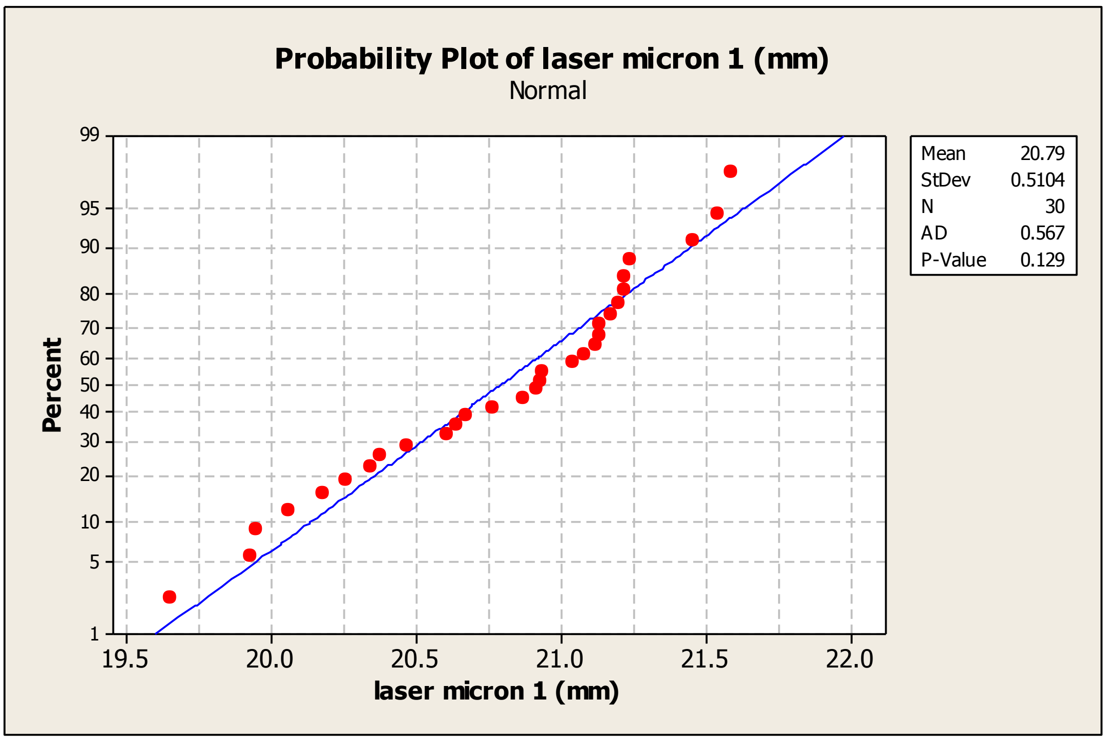


Figure 5: Probability Plot of Laser Micron 1

According to Figure 6, the standard deviation of laser micro camera 2 is 0.8431, is much higher than laser micro camera 1 that means the values more widely spread around the mean. Then the Anderson-Darling value is 0.866 which higher than 0.75, the P Value is 0.023 which lower than 0.05 means the data is not normally distributed.

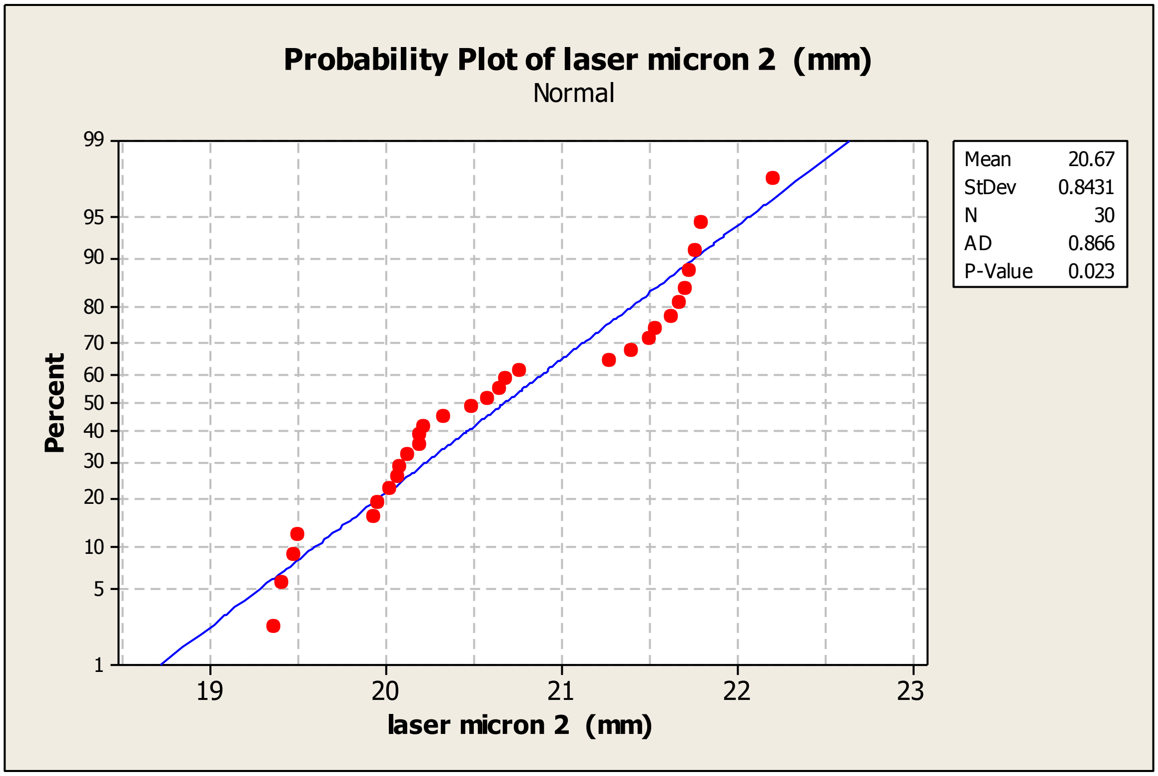


Figure 6: Probability Plot of Laser Micron 2

According to Figure 7, the standard deviation of manual measurement is 0.5815, is close to the laser micro camera 1 that means them values are similar spread around the mean. Then the Anderson-Darling value is 0.331 which lower than 0.75, the P Value is 0.497 which higher than 0.05 means the data is normally distributed.

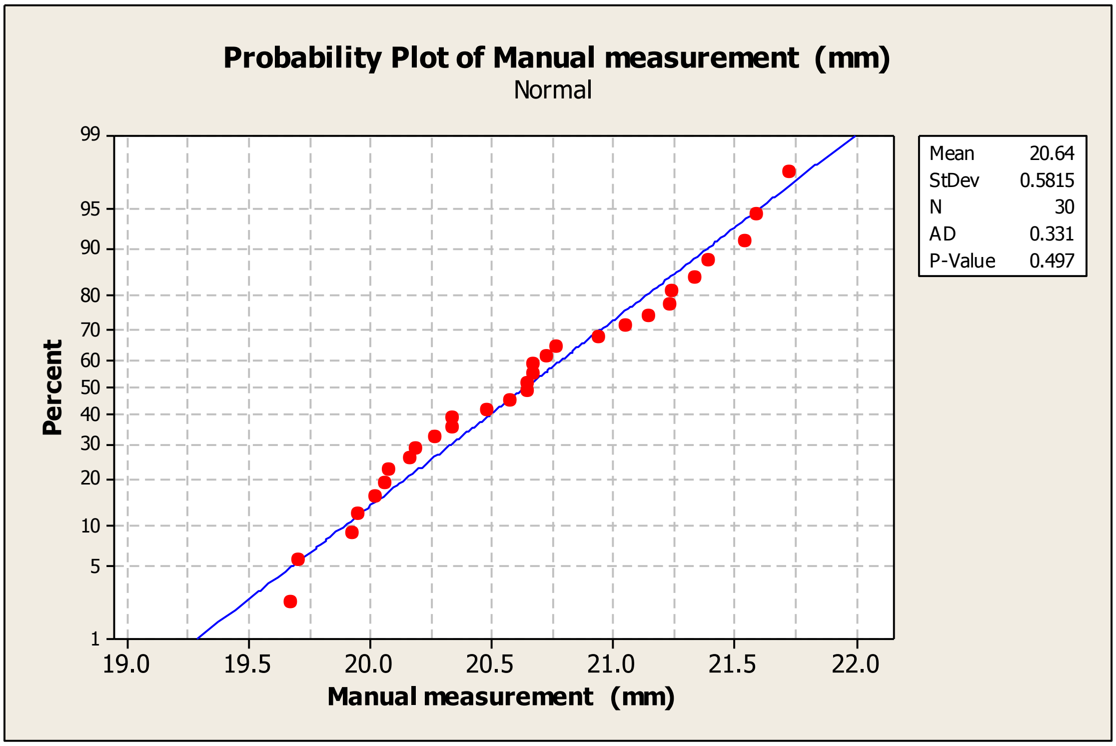


Figure 7: Probability Plot of Manual Measurement

In this study, paired T test and box plot were used to compare and analyze the 3 sets of measurement to each other. Figure 8 can help us to understand the data distribution. The Inter quartile range box represents middle 50% of the data. The range of the reading from laser micro camera 1 is similar with manual measurement. However, the range of the reading from laser micro camera 2 is located all over the tolerance 20+/- 2.5 mm. the next step was compare each paired of data by used paired T test. Since the paired T test only can compare two sets of data, so the paired T test have been conducted 3 times for the 3 sets data: laser micro camera 1 with laser macro camera 2, laser micro camera 1 with manual measurement, and laser micro 2 with manual measurement.

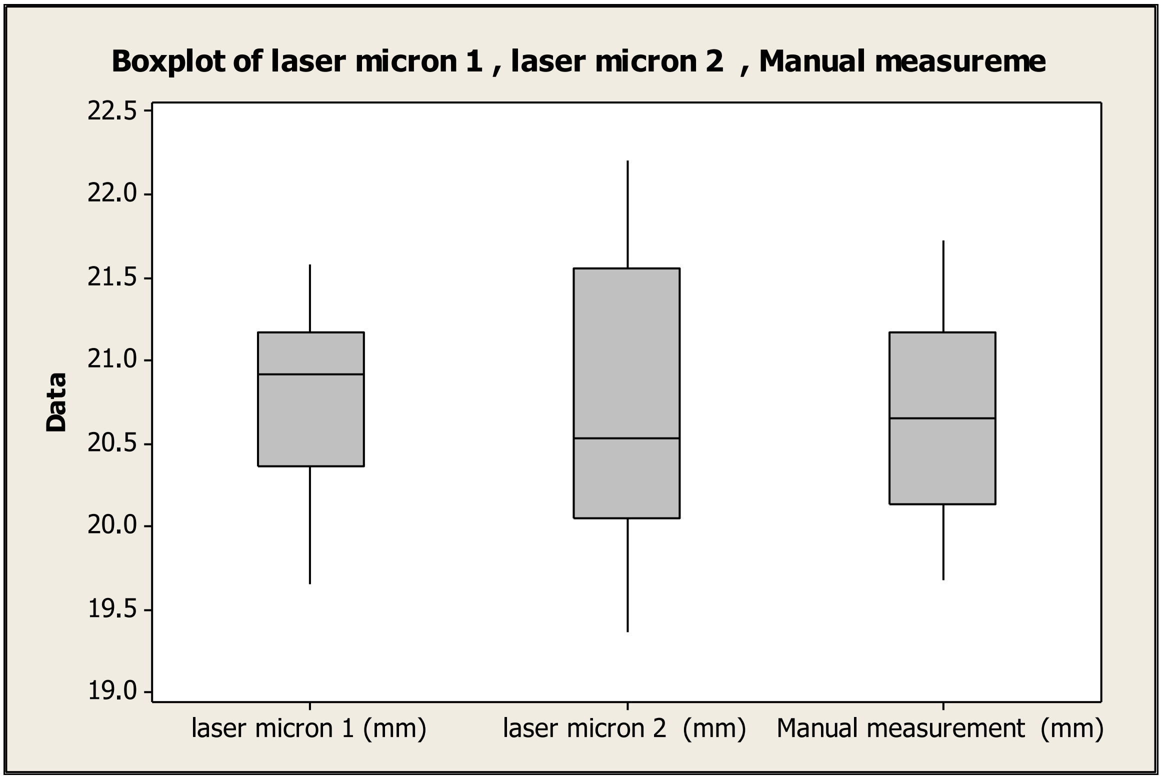


Figure 8: Box Plot of 3 Sets Proximal Ablation Length Measurement

Suggested null and alternative hypotheses could be; H0, there is no mean difference between the two sets of data. H1, there is a mean difference between the two sets of data.

Table 13 shows the laser micro camera 1 with laser macro camera 2 obtained a P value equal to 0.398 which is higher than 0.05. This means there is a 39.8% chance of observing a difference as large as the data observed even if the two measurement means are identical. Therefore, it failed to reject the null hypothesis with this data, and conclude that there is no sufficient evidence to suggest a difference between measurements from laser micro camera 1 and laser macro camera 2.

Table 14 shows the laser micro camera 1 with manual measurement obtained a P value equal to 0.211 which is higher than 0.05. This means there is a 21.1% chance of observing a difference as large as the data observed even if the two measurement means are identical. Therefore, it failed to reject the null hypothesis with this data, and conclude that there is no sufficient evidence to suggest a difference between measurements from laser micro camera 1 and manual measurement.

Table 15 shows the laser micro camera 2 with manual measurement obtained a P value equal to 0.752 which is higher than 0.05. This means there is a 75.2% chance of observing a difference as large as the data observed even if the two measurement means are identical. Therefore, it failed to reject the null hypothesis with this data, and conclude that there is no sufficient evidence to suggest a difference between measurements from laser micro camera 1 and manual measurement.

Table 13: Paired T-Test and CI for Laser Micro Camera 1 with Laser Micro Camera 2

```
Paired T for laser micron 1 (mm) - laser micron 2  (mm)

                        N    Mean  StDev  SE Mean
laser micron 1 (mm)    30  20.787  0.510    0.093
laser micron 2  (mm)   30  20.672  0.843    0.154
Difference             30   0.115  0.734    0.134


95% CI for mean difference: (-0.159, 0.389)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.86  P-Value = 0.398
```

Table 14: Paired T-Test and CI for Laser Micro Camera 1 with Manual Measurement

Paired T for laser micron 1 (mm) - Manual measurement (mm)

	N	Mean	StDev	SE Mean
laser micron 1 (mm)	30	20.787	0.510	0.093
Manual measurement (mm)	30	20.638	0.582	0.106
Difference	30	0.149	0.640	0.117

95% CI for mean difference: (-0.090, 0.388)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.28 P-Value = 0.211

Table 15: Paired T-Test and CI for Laser Micro Camera 2 with Manual Measurement

Paired T for laser micron 2 (mm) - Manual measurement (mm)

	N	Mean	StDev	SE Mean
laser micron 2 (mm)	30	20.672	0.843	0.154
Manual measurement (mm)	30	20.638	0.582	0.106
Difference	30	0.034	0.589	0.107

95% CI for mean difference: (-0.185, 0.254)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.32 P-Value = 0.752

Based on the results above, a conclusion can be made: Since the data from laser micro camera 1 and manual measurement were normally distributed but the data from laser micro camera 2 was not normally distributed, it suggested the inline inspect system obtaining data from laser micro camera 1 can be trusted. Therefore, the study would move to the next step which was conducting the DOE for identify and reduce the factors cause the ablation length variation.

Design of experiments. The DOE results were analyzed by using Minitab. First, running Minitab and choose DOE to Taguchi. Create a Taguchi Design, choose mixed level design, and define the eight factors. After entry raw data into worksheet, choose Nominal is Best and restore the Signal to Noise Ratios, then analyze the data. Table 16, 17, and 18 are the response results from Minitab.

Table 16: Response Table for S/N Ratios

Taguchi Analysis: yield 1, yield 2, ... versus Stabilizer O, Carroage Acc, ...

Response Table for Signal to Noise Ratios
Nominal is best (10*Log10(Ybar**2/s**2))

Level	Stabilizer Oscillation	Carroage Acceleration	Carriage Velocity	Carriage Deceleration	Carriage Jaw Pressure	Collet Jaw Pressure
1	28.34	29.36	28.96	29.56	29.27	28.84
2	30.23	27.83	30.29	29.24	27.03	30.77
3		30.67	28.61	29.05	31.55	28.25
Delta	1.90	2.83	1.68	0.51	4.51	2.51
Rank	6	3	7	8	1	5

Level	Payout Torque	Payout Angular Velocity
1	30.65	30.24
2	30.34	27.69
3	26.87	29.92
Delta	3.78	2.55
Rank	2	4

Table 17: Response Table for Means

Response Table for Means

Level	Stabilizer Oscillation	Carroage Acceleration	Carriage Velocity	Carriage Deceleration	Carriage Jaw Pressure	Collet Jaw Pressure
1	20.57	20.73	20.66	20.74	20.51	20.49
2	20.62	20.61	20.58	20.59	20.60	20.61
3		20.45	20.55	20.46	20.68	20.69
Delta	0.06	0.27	0.11	0.28	0.17	0.21
Rank	8	2	7	1	5	3

Level	Payout Torque	Payout Angular Velocity
1	20.63	20.50
2	20.68	20.66
3	20.48	20.62
Delta	0.20	0.16
Rank	4	6

Table 18: Results for S/N Ratios, Standard Deviations and Means

No. of experiment	camera 1							
	yield 1	yield 2	yield 3	yield 4	yield 5	SNRA	STDE	MEAN
1	20.744	21.113	19.59	21.133	20.631	30.329	0.629	20.642
2	20.448	21.822	19.735	20.796	21.392	28.173	0.813	20.839
3	20.23	20.248	21.227	19.511	21.825	27.064	0.914	20.608
4	19.661	21.705	20.049	22.069	19.734	25.070	1.152	20.644
5	20.177	21.172	20.219	21.168	20.359	32.177	0.507	20.619
6	20.147	20.173	19.856	22.018	19.216	25.766	1.044	20.282
7	20.584	21.549	19.863	21.26	20.096	29.087	0.726	20.670
8	19.363	20.282	21.555	18.717	20.219	25.431	1.072	20.027
9	21.546	20.351	20.966	20.798	20.231	31.931	0.526	20.778
10	20.943	20.891	20.188	20.698	21.102	35.390	0.353	20.764
11	20.905	21.837	19.646	21.788	20.043	26.426	0.995	20.844
12	21.226	19.634	21.427	20.152	20.872	28.775	0.752	20.662
13	19.447	22.168	21.015	21.028	19.714	25.427	1.107	20.674
14	19.952	20.132	21.083	20.501	20.989	32.227	0.502	20.531
15	21.065	19.922	21.813	19.75	21.866	26.319	1.009	20.883
16	20.633	20.072	21.004	21.477	19.493	28.438	0.777	20.536
17	20.995	20.752	20.298	20.679	20.392	37.295	0.282	20.623
18	20.031	20.579	19.766	20.624	19.433	31.808	0.516	20.087

Figure 9 Main Effect Plot for S/N ratios shows the optimum setting for minimize noises; the Stabilizer Oscillation at position 2 which is off, the Carriage Acceleration at position 3 which is 1750, the Carriage Velocity at position 2 which is 500, the Carriage Deceleration at position 1 which is 250, the Carriage Jaw Pressure at position 3 which is 90, the Collet Jaw Pressure at position 2 which is 60, the Payout Torque at position 1 which is 75%, and the Payout Angular Velocity at position 1 which is 50.

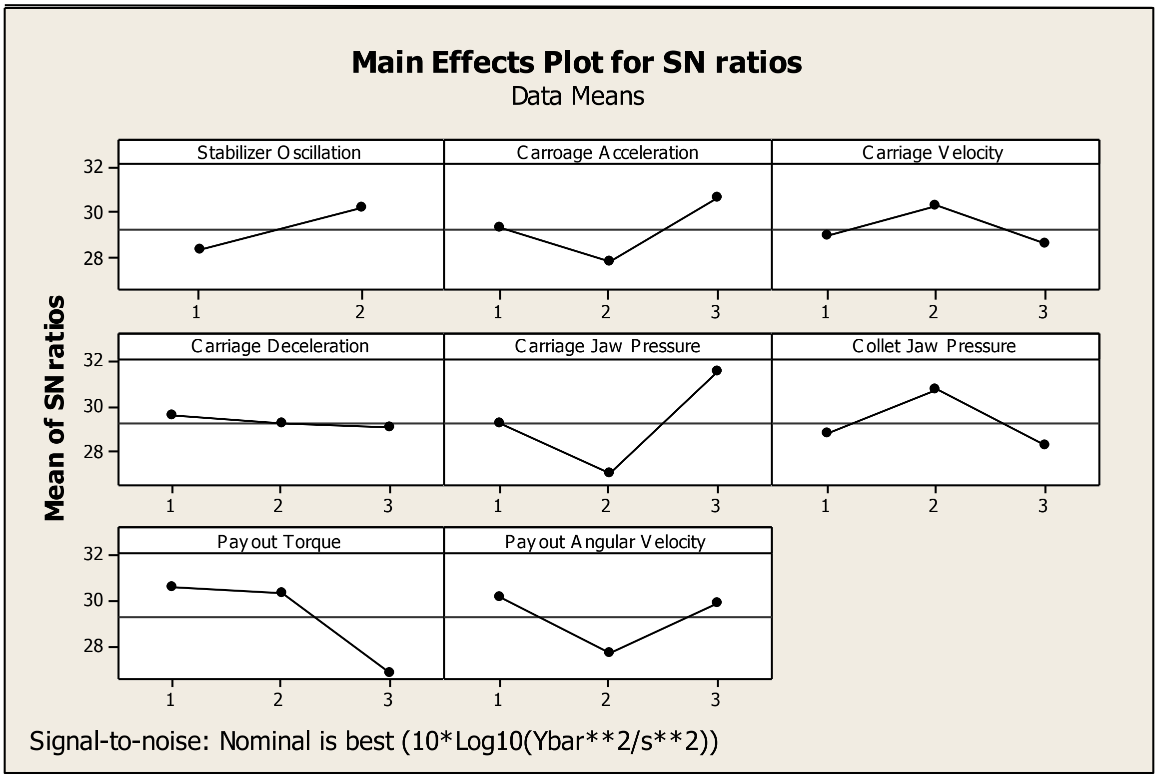


Figure 9: Main Effects Plot for S/N Ratios

Figure 10 Main Effect Plot for means shows Carriage Acceleration, Carriage Deceleration, Carriage Jaw Pressure, Collet Jaw Pressure, Payout Torque and Payout Angular Velocity factors have the more variability and the Stabilizer Oscillation and Carriage Velocity factors have the less variability.

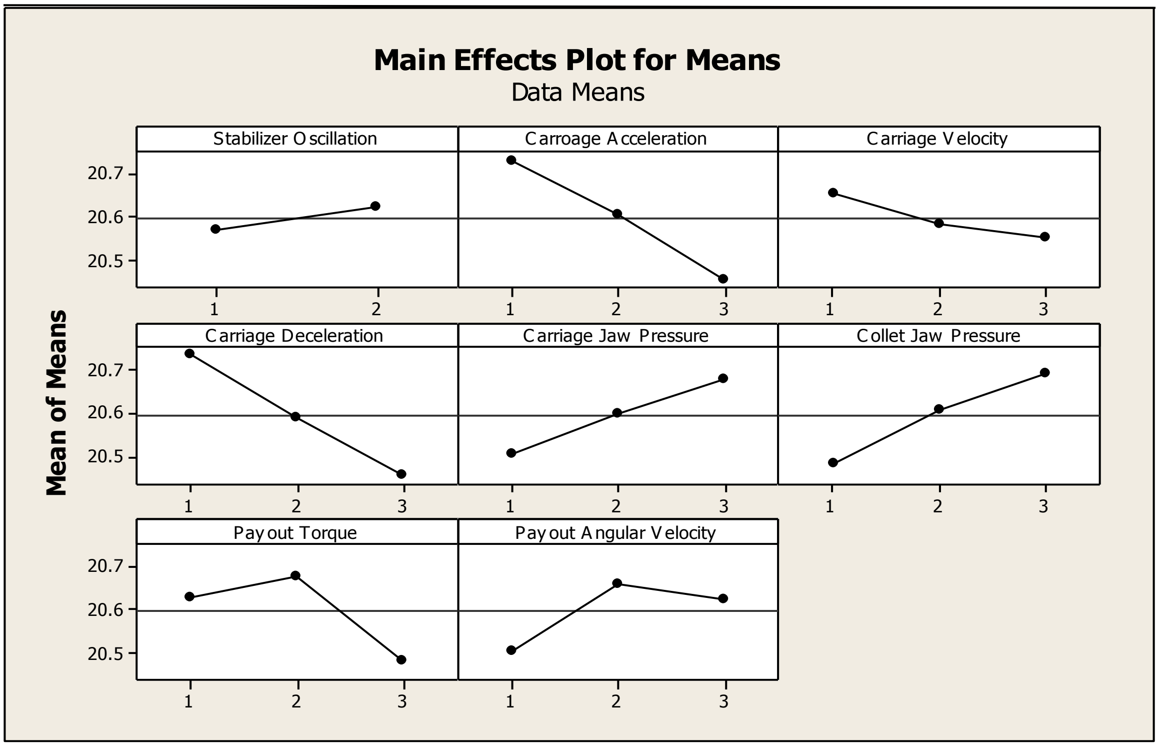


Figure 10: Main Effects Plot for Means

The next step was using the Minitab's General Linear Model for ANOVA analysis to determine the F-value. The result is shown on Table 19.

Table 19: ANOVA Analysis Results

Analysis of Variance for SNRA1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Stabilizer Oscillation	1	16.200	16.200	16.200	3.74	0.193
Carroage Acceleration	2	24.149	24.149	12.074	2.79	0.264
Carriage Velocity	2	9.413	9.413	4.707	1.09	0.479
Carriage Deceleration	2	0.794	0.794	0.397	0.09	0.916
Carriage Jaw Pressure	2	61.102	61.102	30.551	7.05	0.124
Collet Jaw Pressure	2	20.775	20.775	10.387	2.40	0.294
Payout Torque	2	52.739	52.739	26.370	6.09	0.141
Payout Angular Velocity	2	23.114	23.114	11.557	2.67	0.273
Error	2	8.666	8.666	4.333		
Total	17	216.953				

S = 2.08163 R-Sq = 96.01% R-Sq(adj) = 66.05%

Since the Stabilizer Oscillation, Carriage Velocity, Carriage Deceleration, and Collet Jaw Pressure factors are less than 10% of Total Sum of square (SS). Assume the factors are noises and add to error to get pooled (Error). The F value is used for qualitative understanding of the relative factor effects. Then Interpret the F value in Taguchi for those factors are more than 10% of SS. A value of F less than 1 means the factor effect is smaller than the error of the additive model. After adjusted factors to error, there is no F value of a factor less than 1. A value of F larger than 2 means the factor is not quite small. After adjusted factors to error the factors of Carriage Acceleration, Carriage Jaw Pressure, Payout Torque, and Payout Angular Velocity are still suitable. Among the 5 factors, Carriage Jaw Pressure and Payout Torque are larger than 4 means the two factors effect are quite large.

An interactions plot is a plot of means for each level of a factor with the level of a second factor held constant. Interactions plots are useful for judging the presence of interaction. A matrix of interaction plots for three to nine factors. There is a matrix of interaction plots for the eight factors created by using Minitab. The response was S/N ratios and the factors were all of the 8 factors.

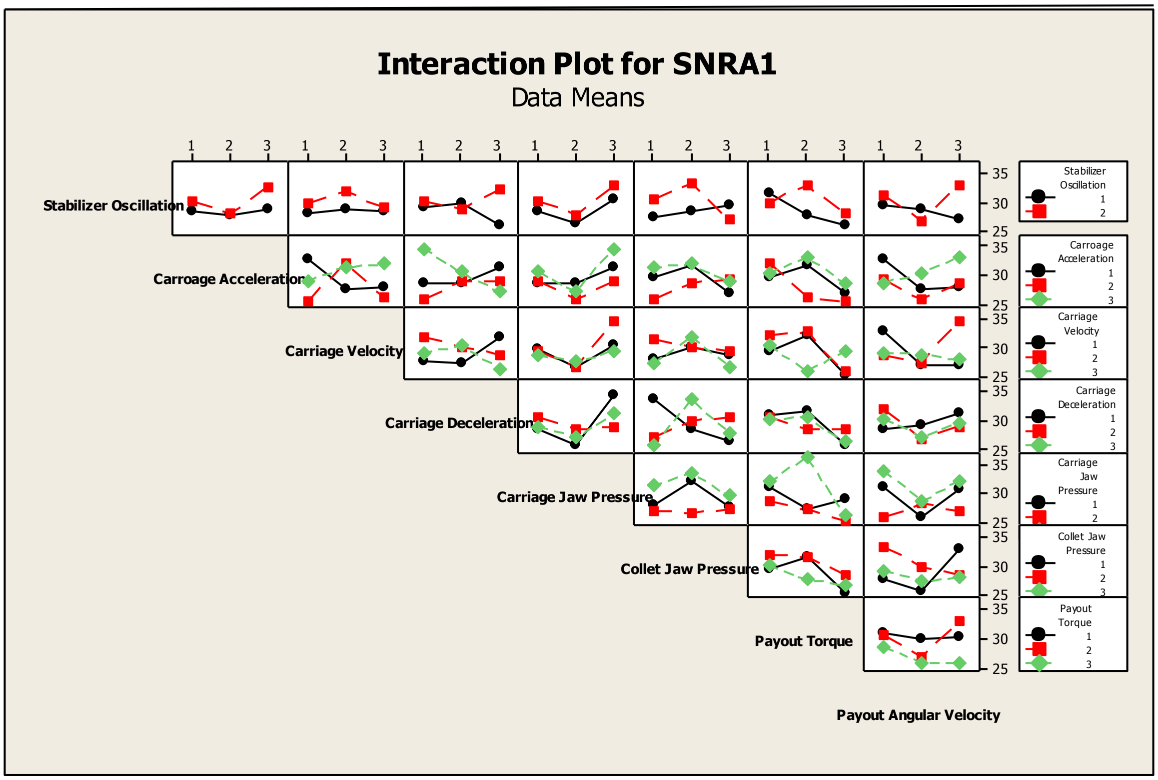
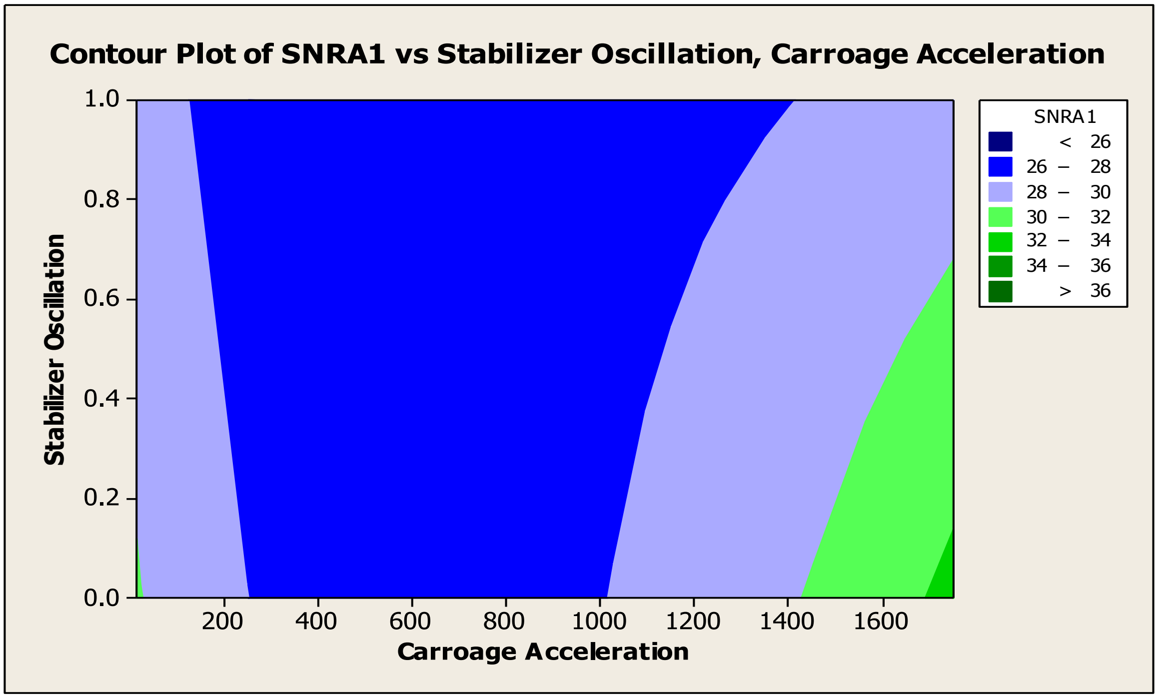
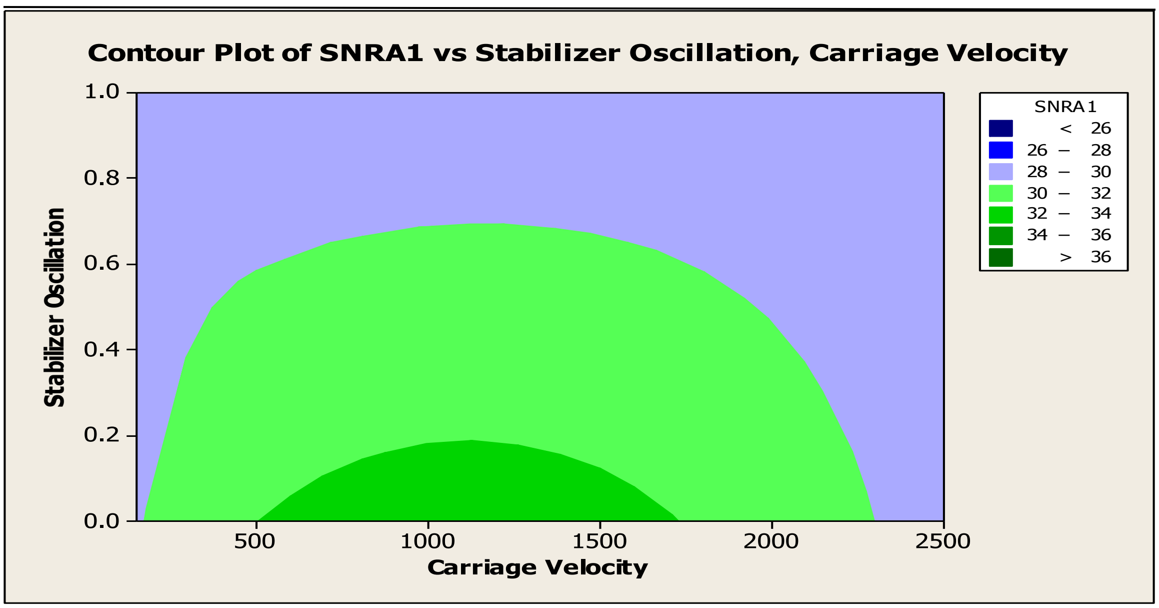


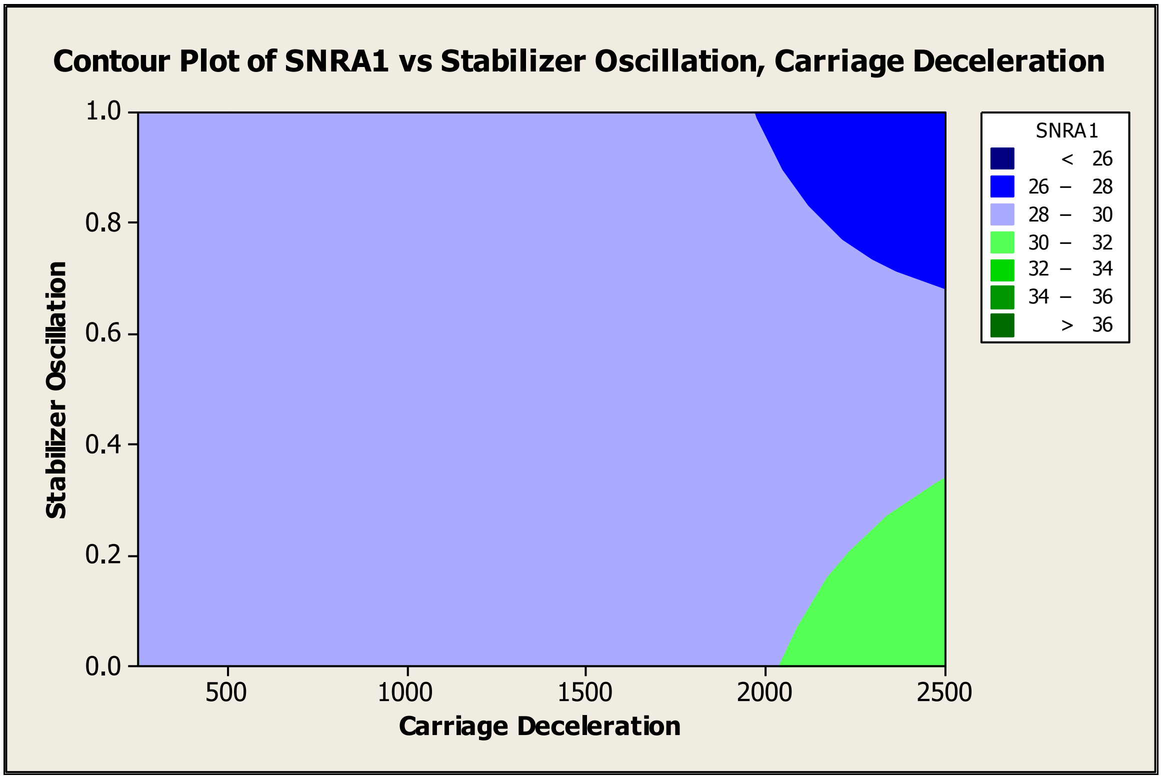
Figure 11: Interaction Plot for S/N Ratios

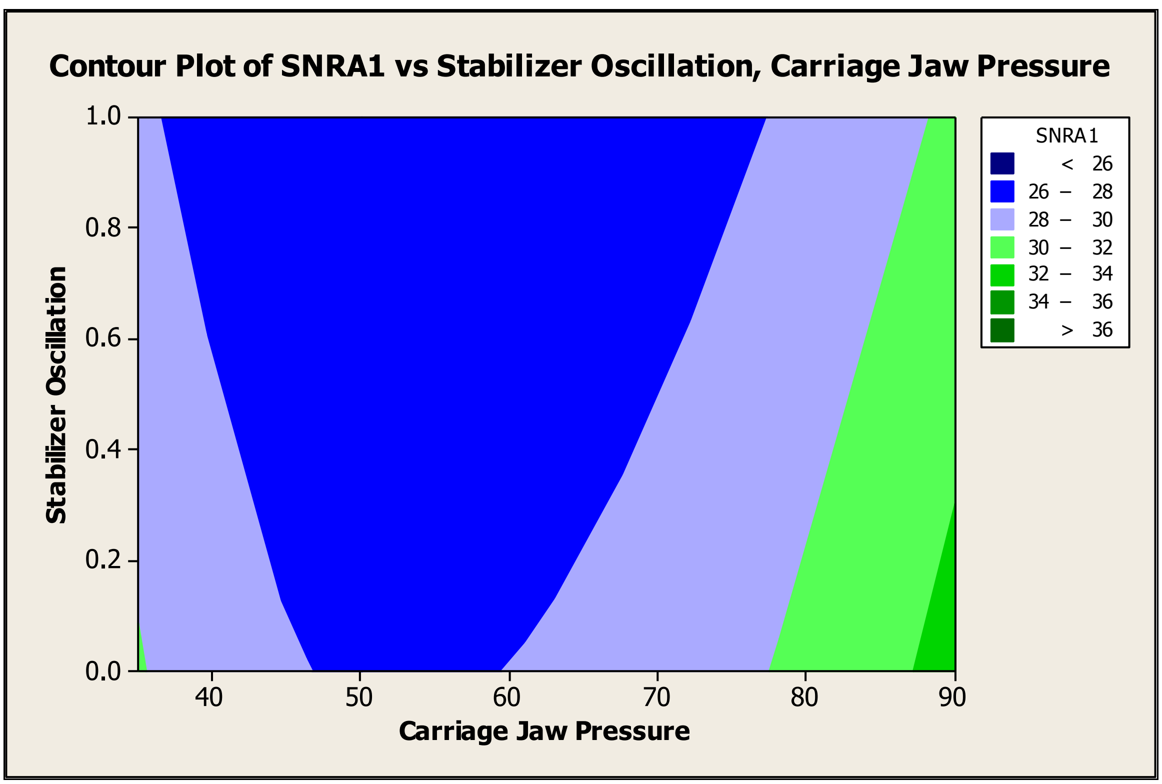
The interaction plot shows there are most anti-synergistic interactions in the table. So there is a strong interaction among control factors and it is harmful (anti synergistic), the direction of a control factor's effect on product's performance or robustness changes when the level of another factor is changed.

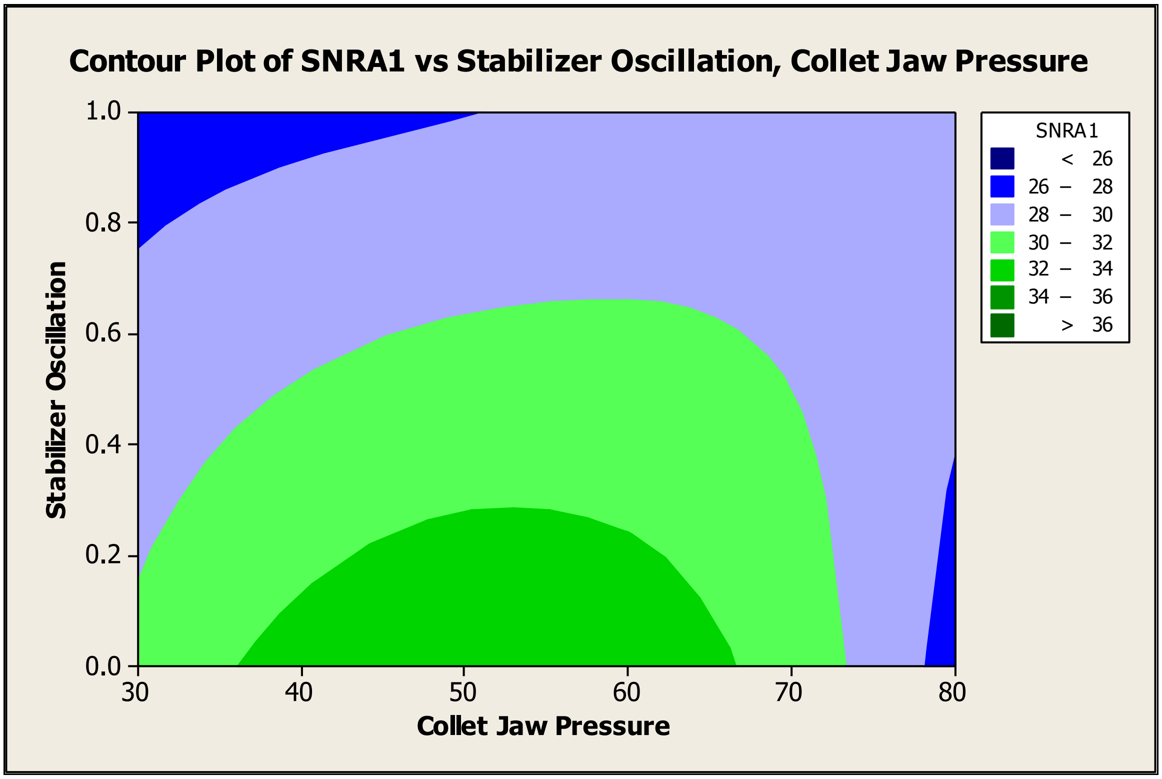
Contour plot is a graphical representation of the possible solutions to the likelihood ratio equation. This is used to determine confidence bounds as well as comparisons between two different data sets. The contour plots were also created by using Minitab. Z variable was using S/N ratios, and Y and X variables selected 2 different factors each time from 8 factors. Therefore there are totally 28 combinations which means 28 contour plots were created shows on Figure 12. In the contour plots, the region under darker green color is the target response. This is the region that the parameter setting for the wire ablation machine should fall in.






Contour Plot of SNRA1 vs Stabilizer Oscillation, Carriage Deceleration
Stabilizer Oscillation
1.0
0.8
0.6
0.4
0.2
0.0
500
1000
1500
2000
2500
Carriage Deceleration
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Stabilizer Oscillation, Carriage Jaw Pressure
Stabilizer Oscillation
1.0
0.8
0.6
0.4
0.2
0.0
40
50
60
70
80
90
Carriage Jaw Pressure
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36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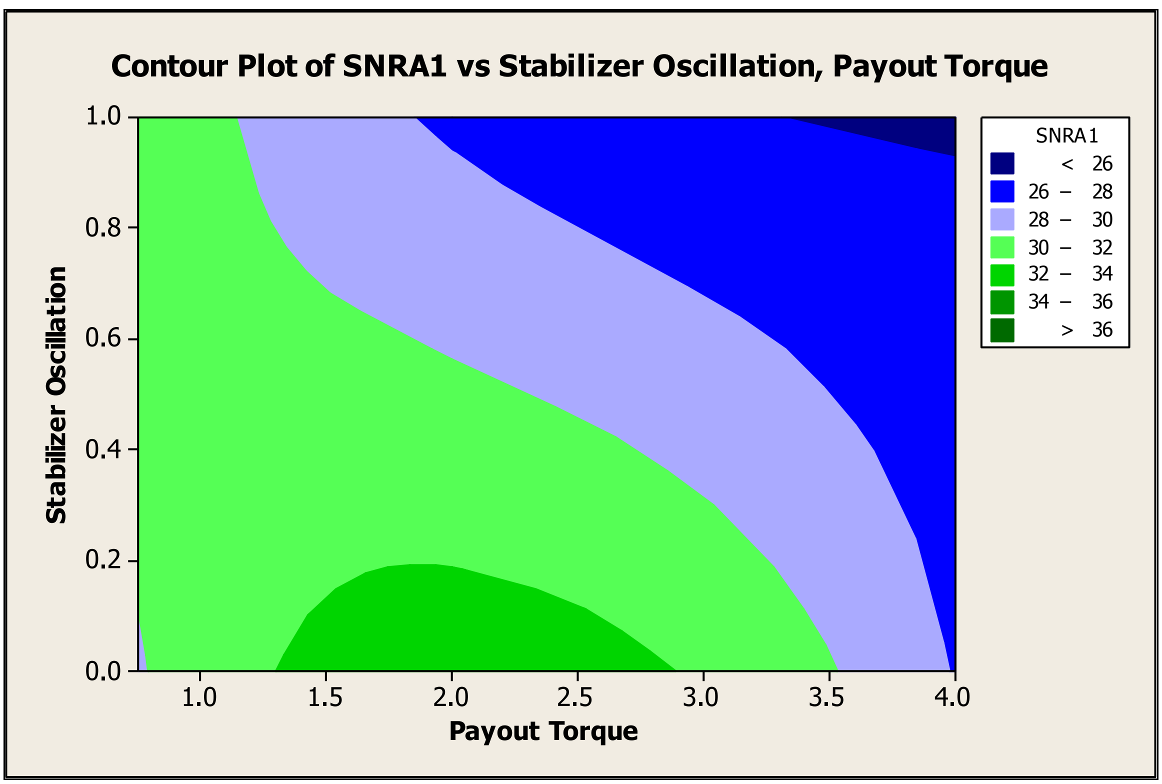
Stabilizer Oscillation
1.0
0.8
0.6
0.4
0.2
0.0
30
40
50
60
70
80
Collet Jaw Pressure
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36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Stabilizer Oscillation
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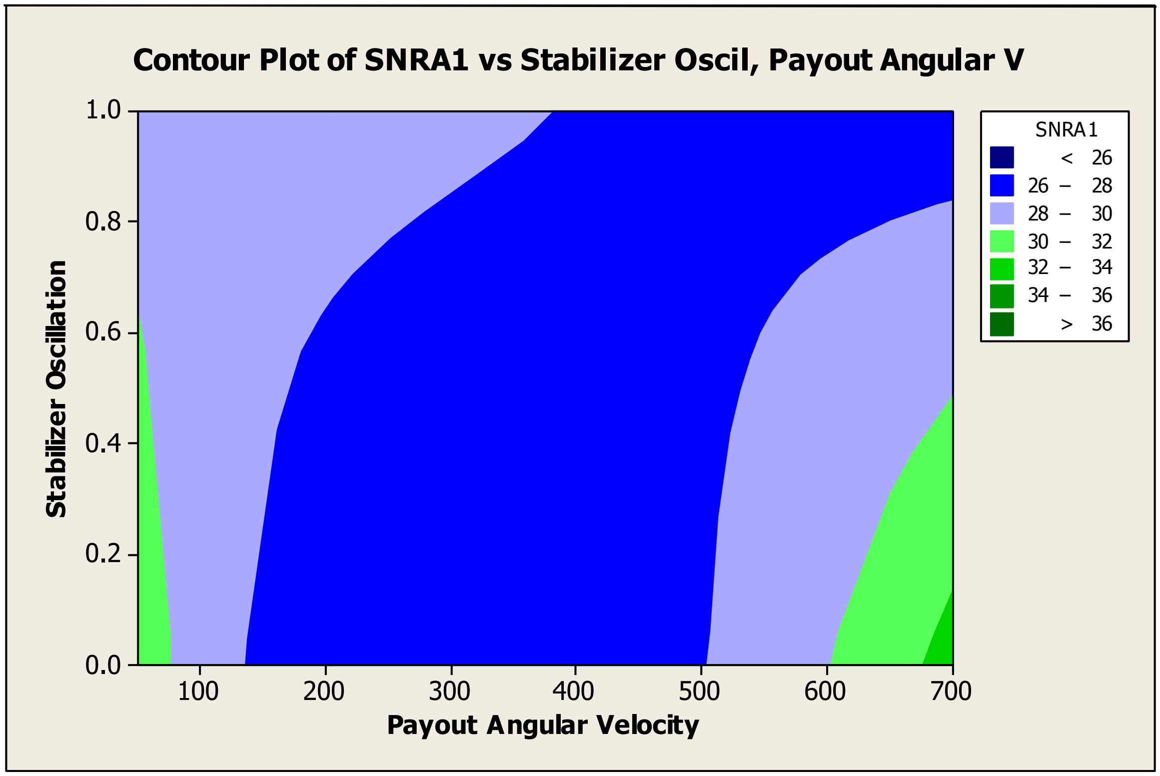
0.6
0.4
0.2
0.0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Payout Torque
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Stabilizer Oscil, Payout Angular V
Stabilizer Oscillation
1.0
0.8
0.6
0.4
0.2
0.0
100
200
300
400
500
600
700
Payout Angular Velocity
SNRA1
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28 – 30
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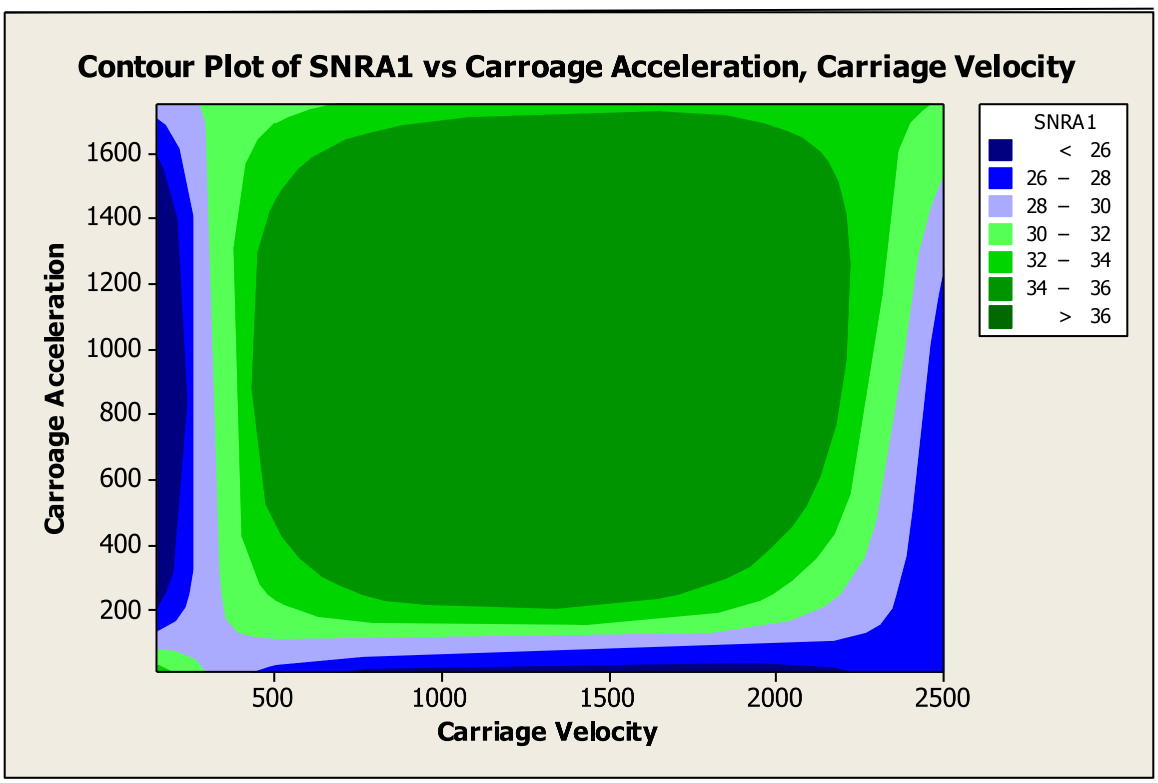
32 – 34
34 – 36
> 36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Carroage Acceleration
1600
1400
1200
1000
800
600
400
200
500
1000
1500
2000
2500
Carriage Velocity
SNRA1
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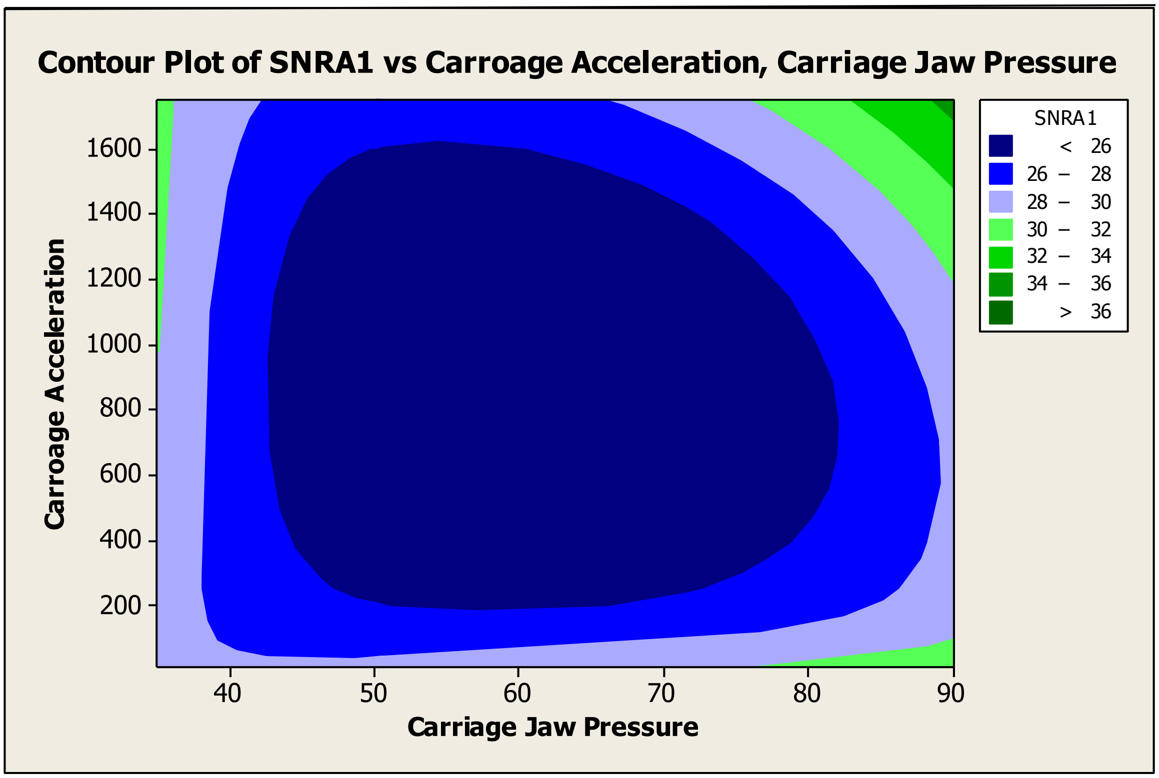
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36



Contour Plot of SNRA1 vs Carroage Acceleration, Carriage Jaw Pressure
Carroage Acceleration
1600
1400
1200
1000
800
600
400
200
40
50
60
70
80
90
Carriage Jaw Pressure
SNRA1
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26 – 28
28 – 30
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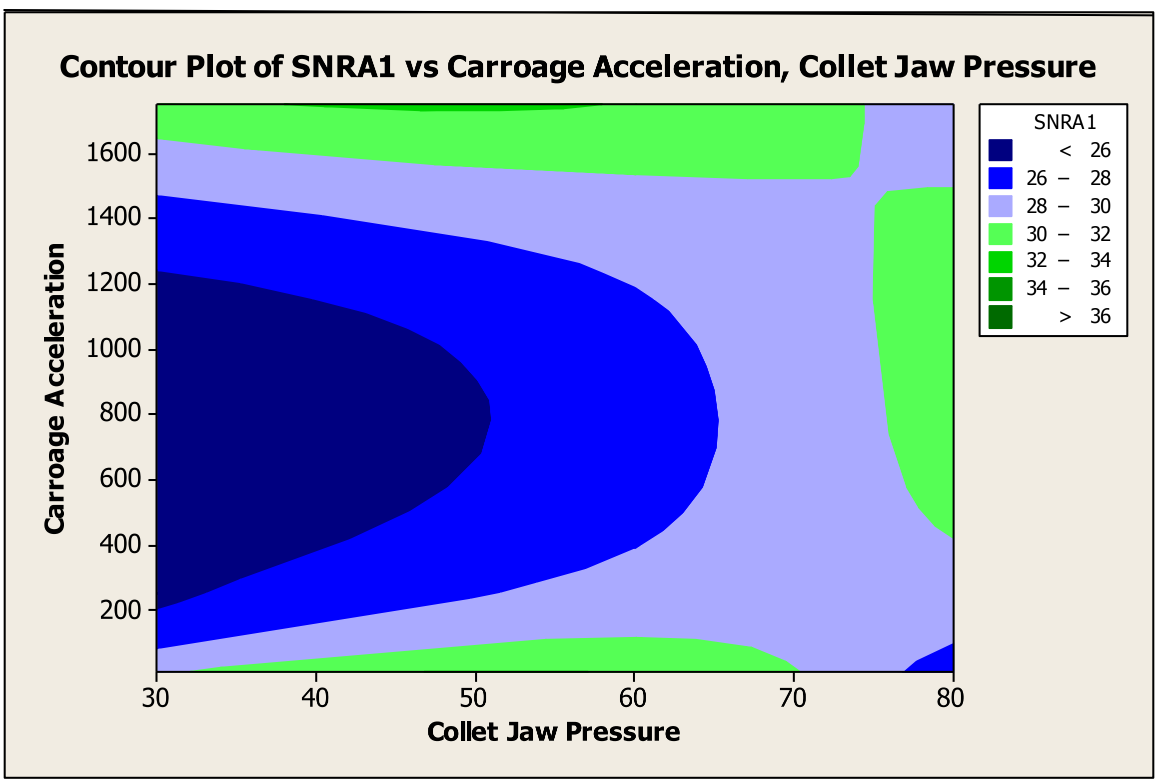
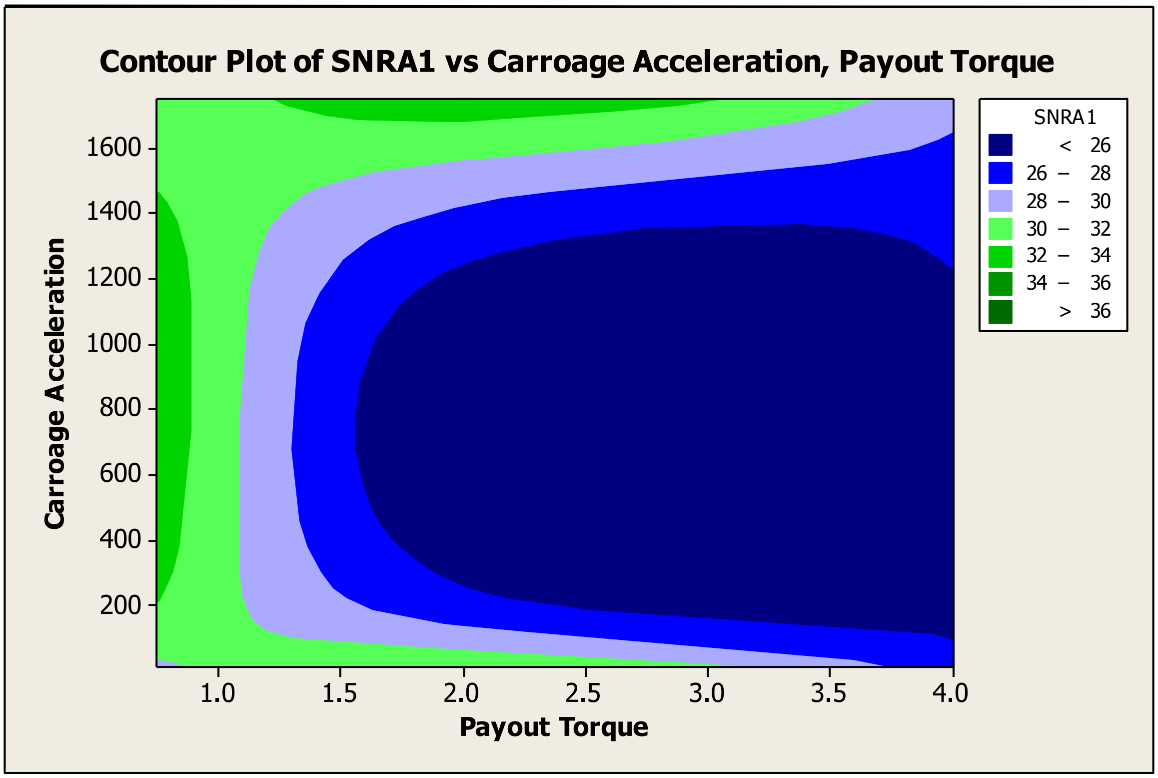
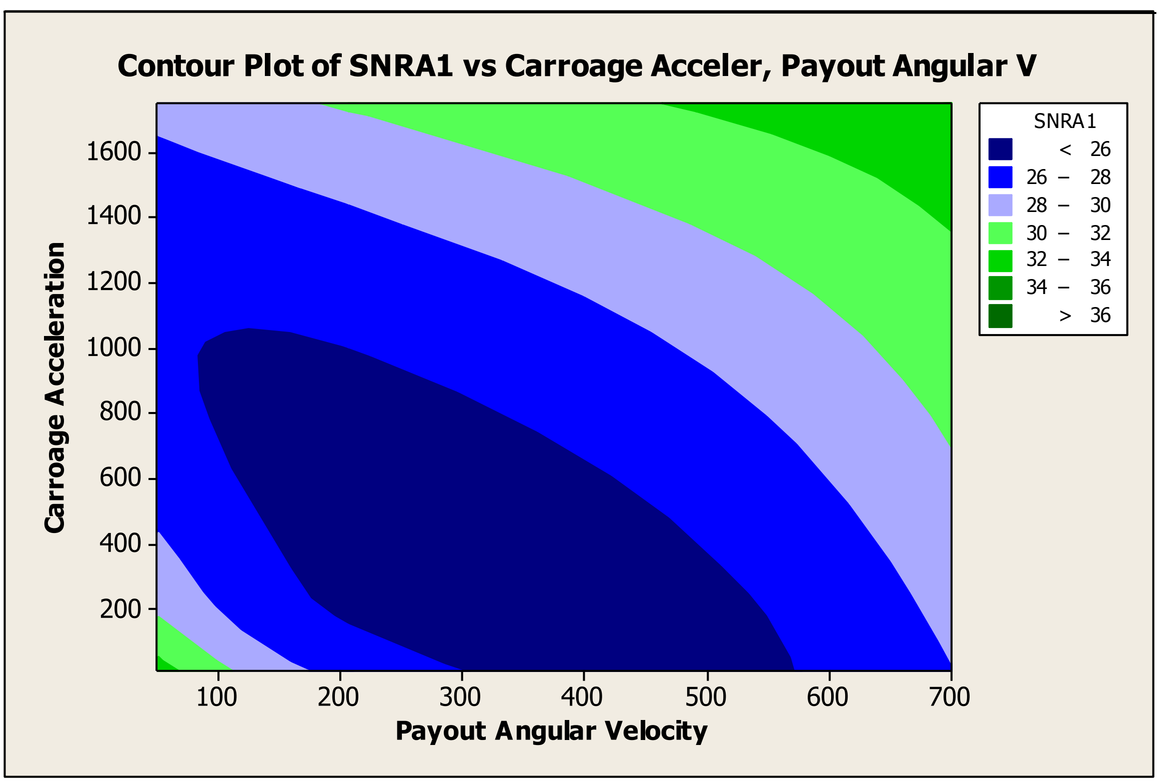
32 – 34
34 – 36
> 36



Contour Plot of SNRA1 vs Carroage Acceleration, Collet Jaw Pressure
Carroage Acceleration
1600
1400
1200
1000
800
600
400
200
30
40
50
60
70
80
Collet Jaw Pressure
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carroage Acceleration, Payout Torque
Carroage Acceleration
Payout Torque
1600
1400
1200
1000
800
600
400
200
1.0
1.5
2.0
2.5
3.0
3.5
4.0
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36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Carroage Acceleration
Payout Angular Velocity
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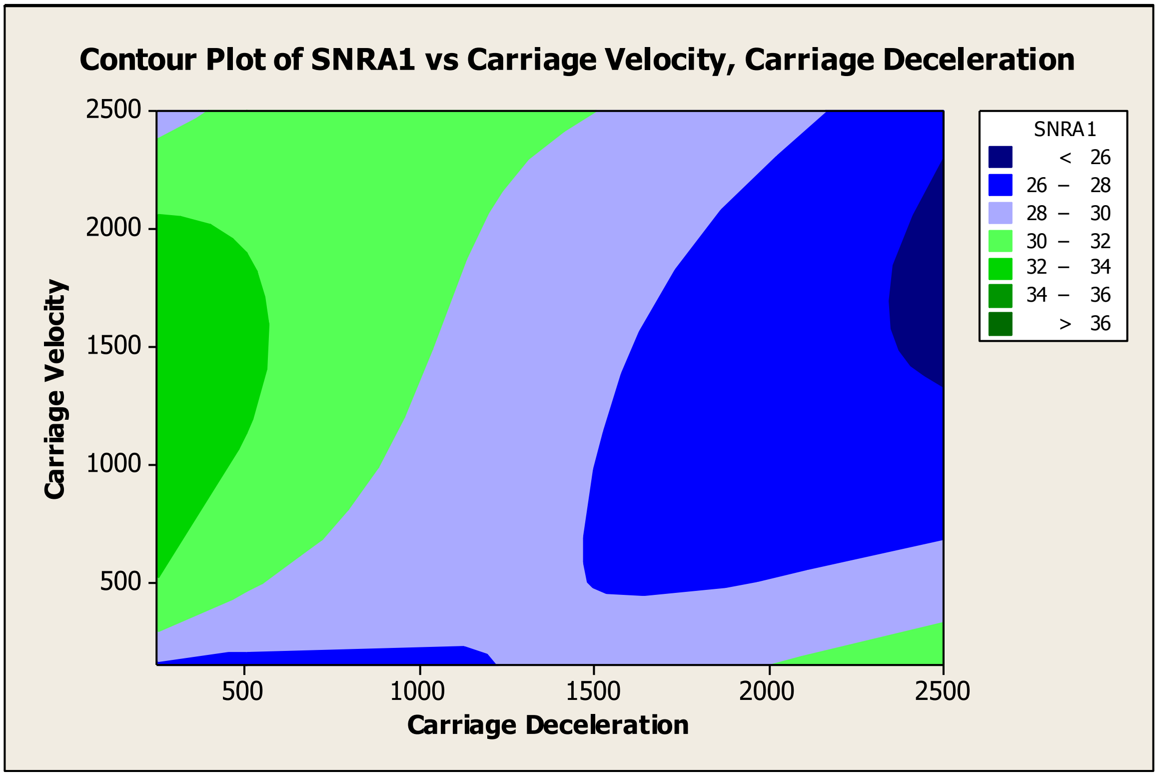
1400
1200
1000
800
600
400
200
100
200
300
400
500
600
700
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Velocity, Carriage Deceleration
Carriage Velocity
2500
2000
1500
1000
500
500
1000
1500
2000
2500
Carriage Deceleration
SNRA1
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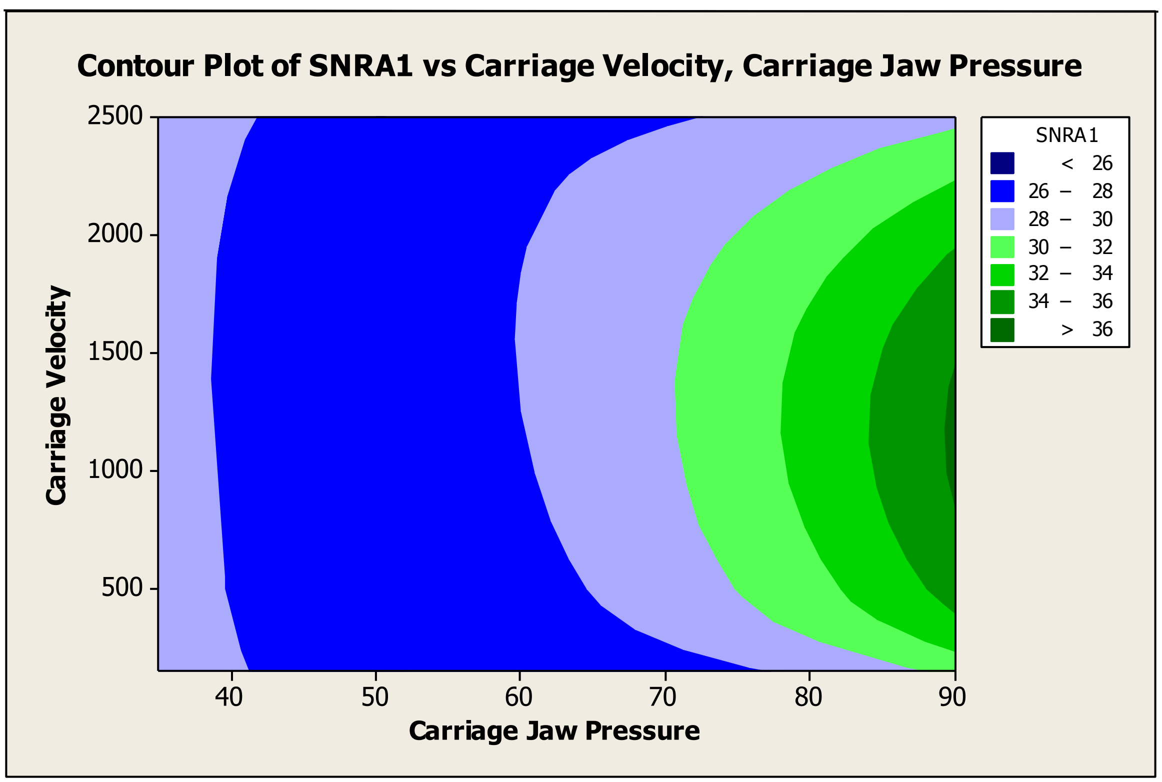
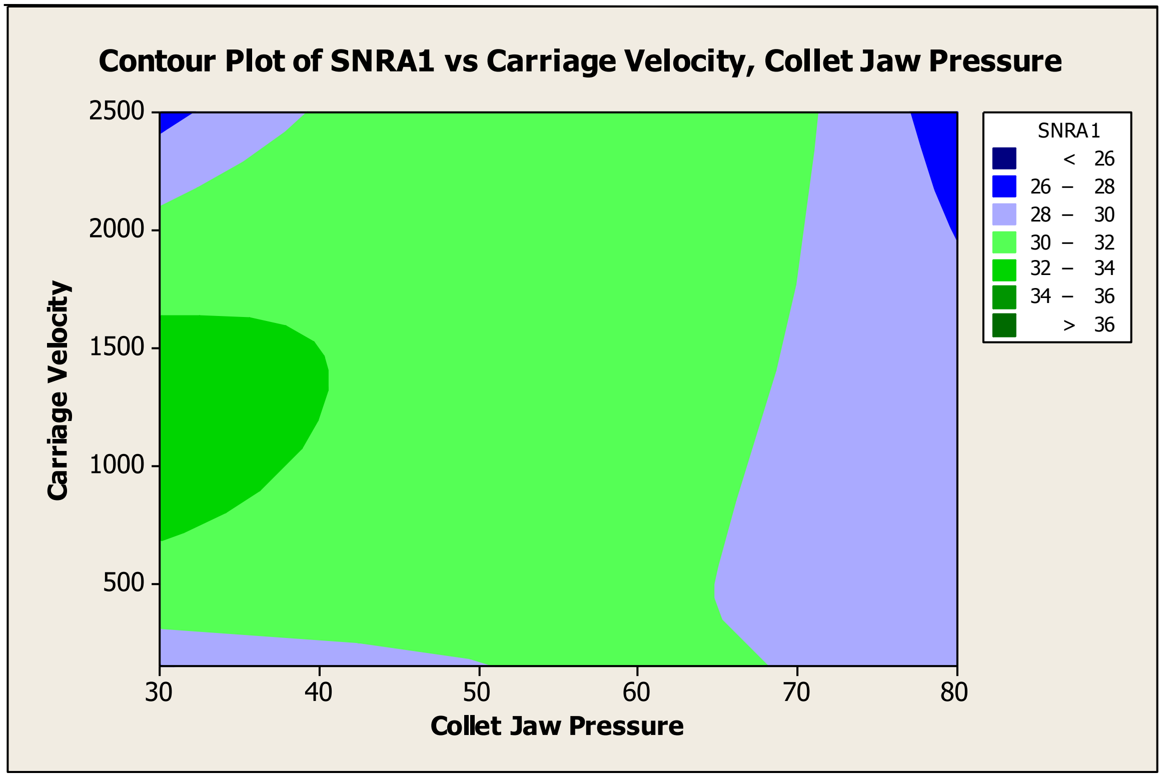
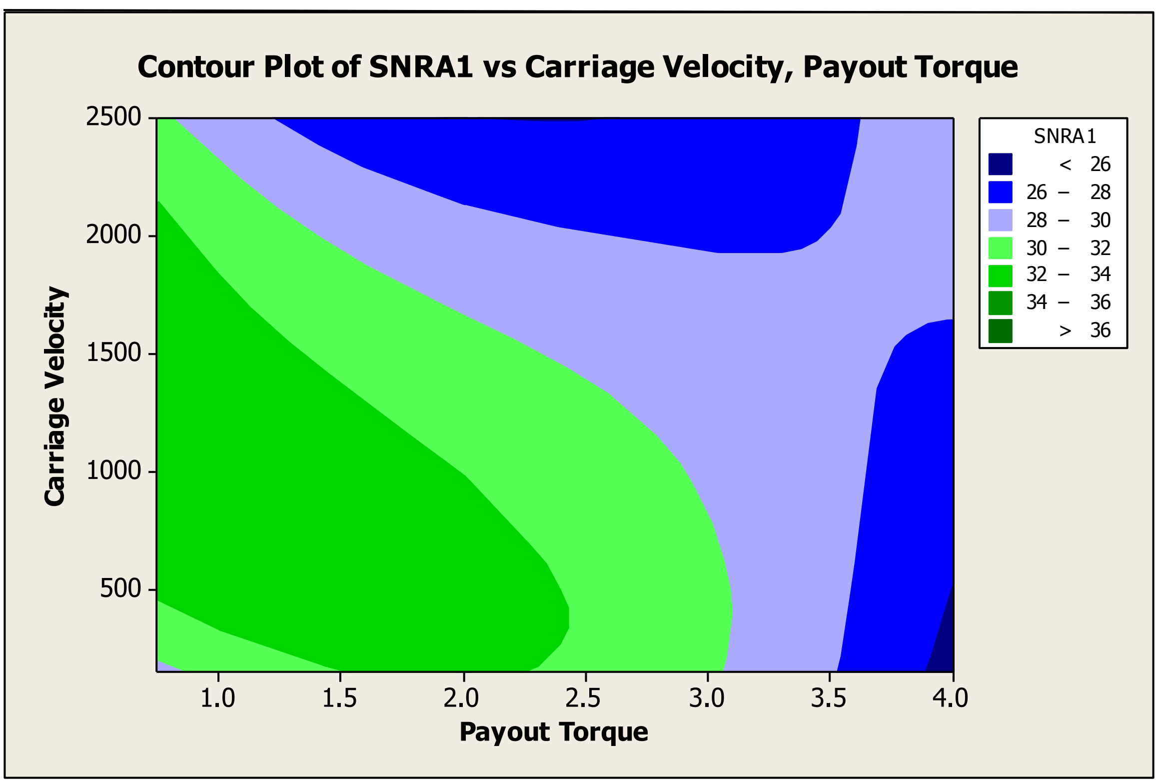
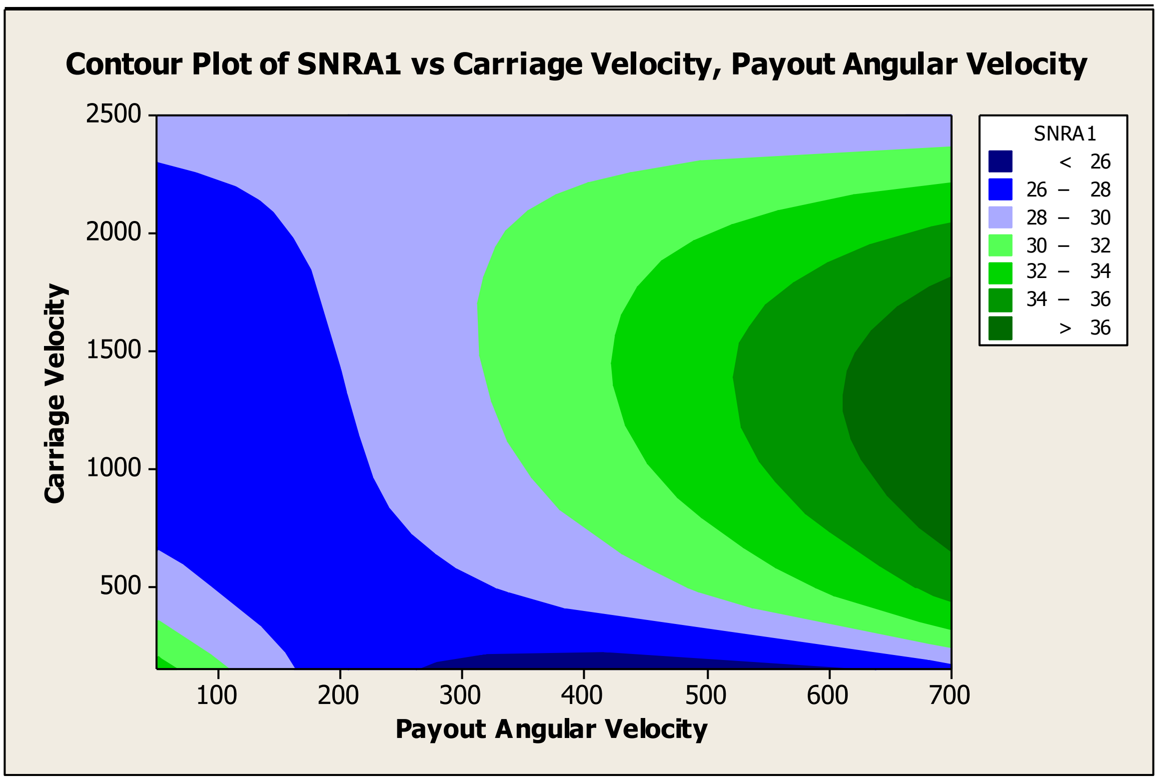
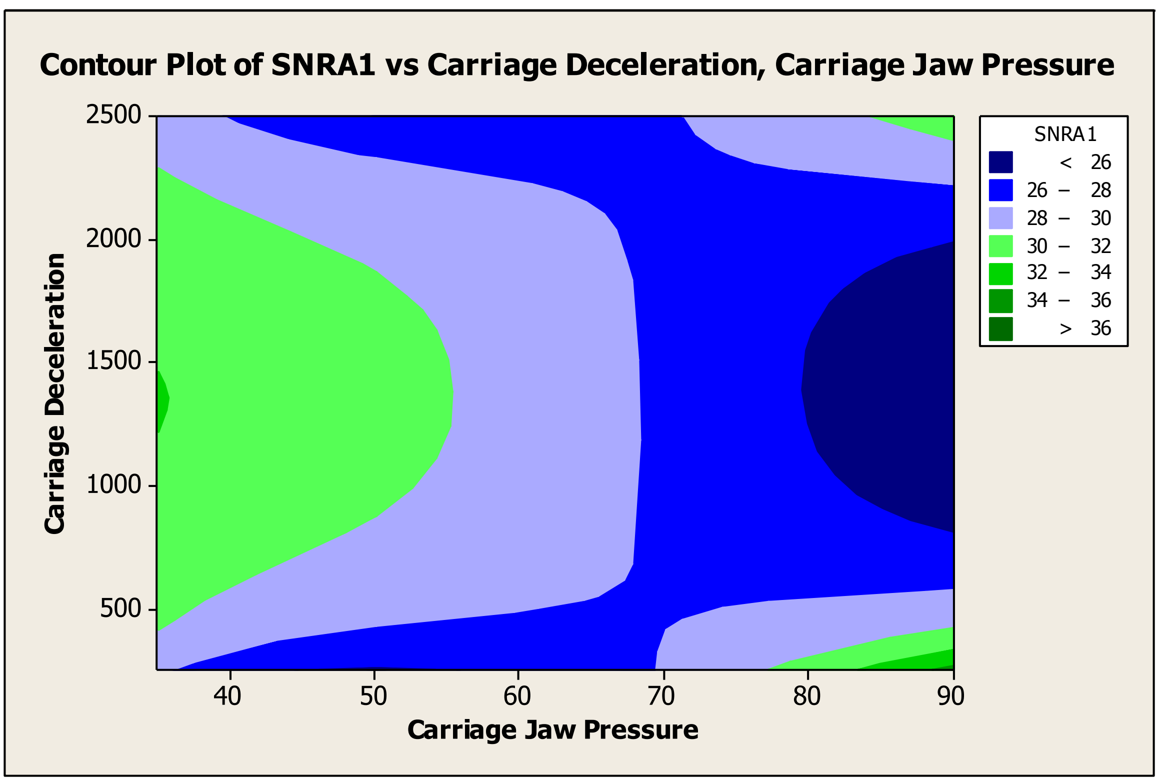
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Velocity, Carriage Jaw Pressure
Carriage Velocity
2500
2000
1500
1000
500
40
50
60
70
80
90
Carriage Jaw Pressure
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Velocity, Collet Jaw Pressure
2500
2000
1500
1000
500
Carriage Velocity
30
40
50
60
70
80
Collet Jaw Pressure
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Velocity, Payout Torque
2500
2000
1500
1000
500
Carriage Velocity
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Payout Torque
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Velocity, Payout Angular Velocity
Carriage Velocity
2500
2000
1500
1000
500
100
200
300
400
500
600
700
Payout Angular Velocity
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Deceleration, Carriage Jaw Pressure
Carriage Deceleration
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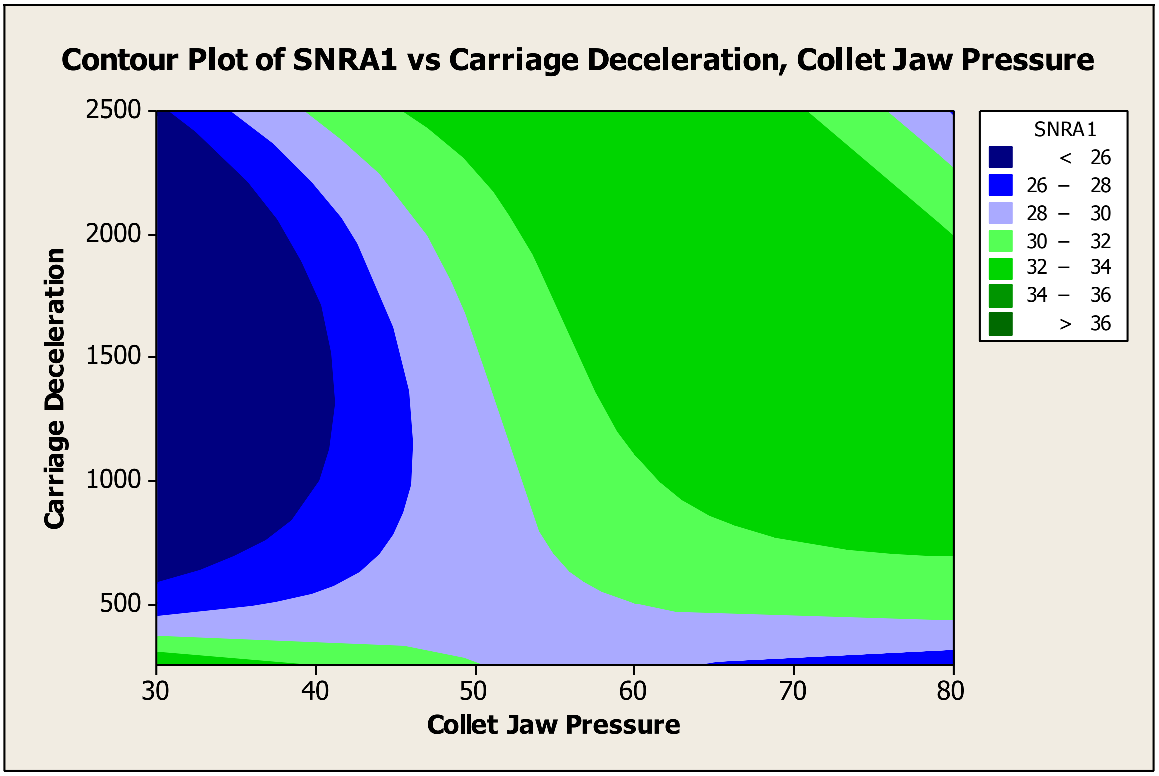
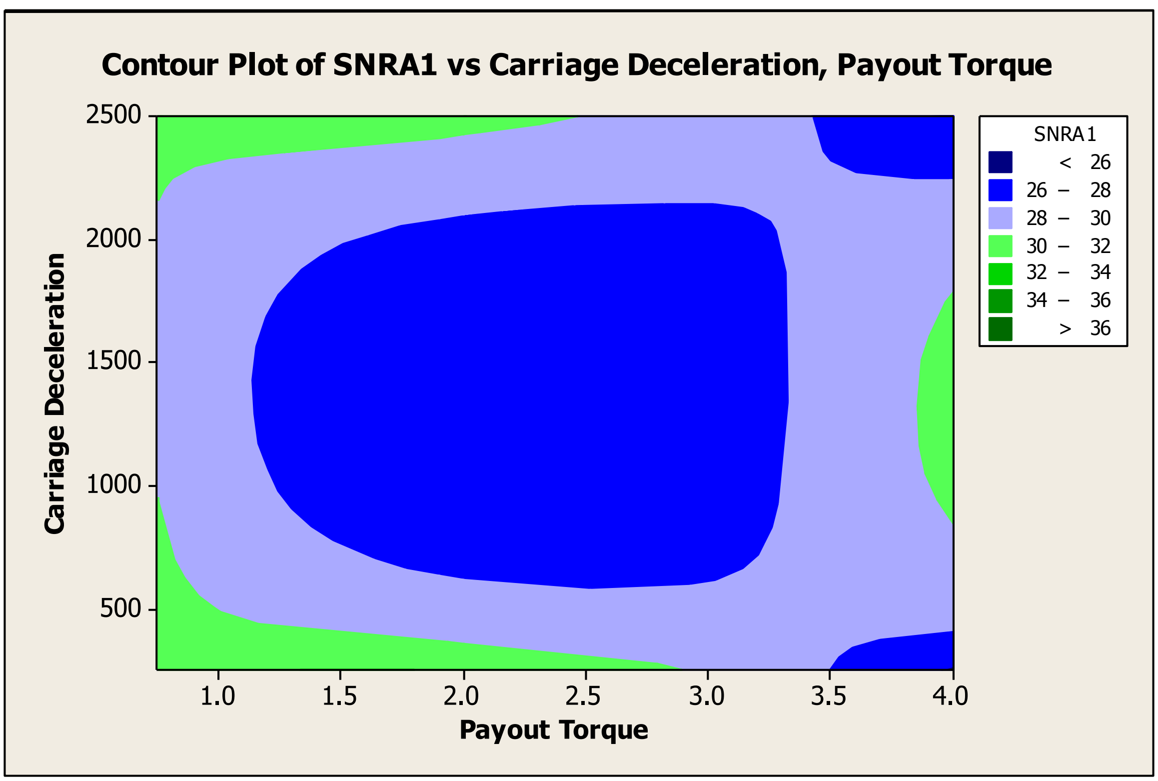
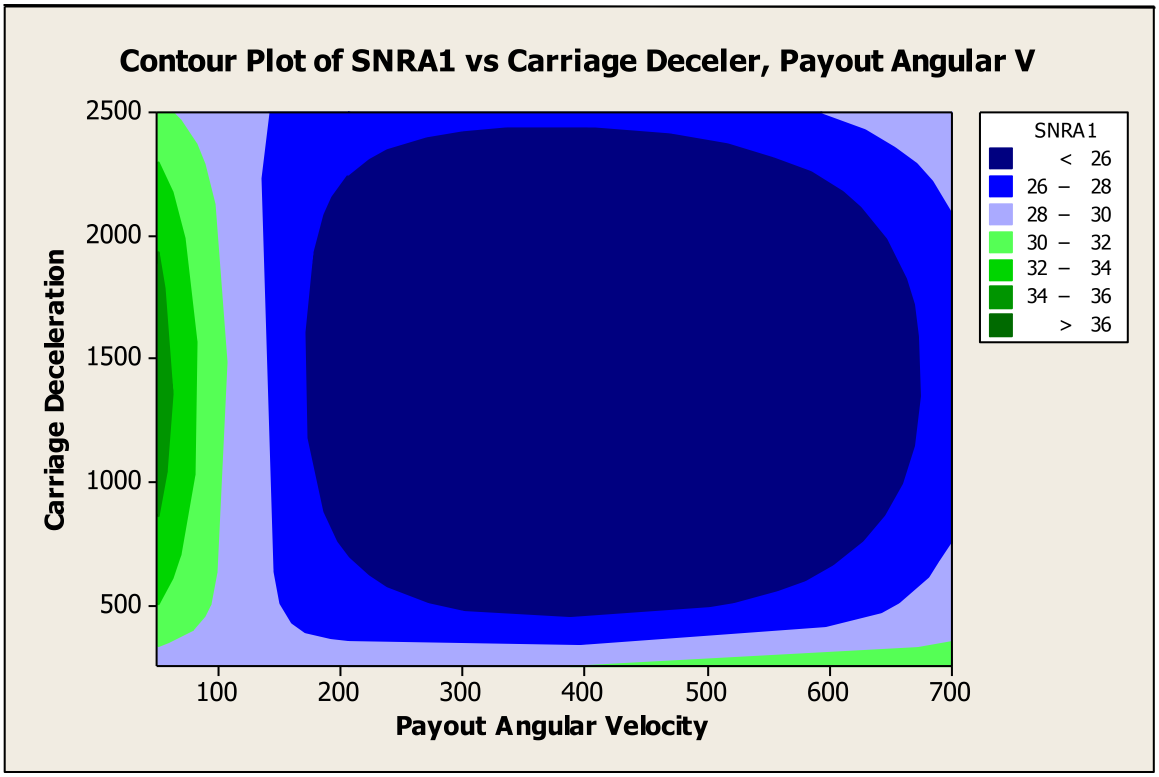
2000
1500
1000
500
40
50
60
70
80
90
Carriage Jaw Pressure
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Deceleration, Collet Jaw Pressure
Carriage Deceleration
Collet Jaw Pressure
2500
2000
1500
1000
500
30
40
50
60
70
80
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Deceleration, Payout Torque
Carriage Deceleration
Payout Torque
2500
2000
1500
1000
500
1.0
1.5
2.0
2.5
3.0
3.5
4.0
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36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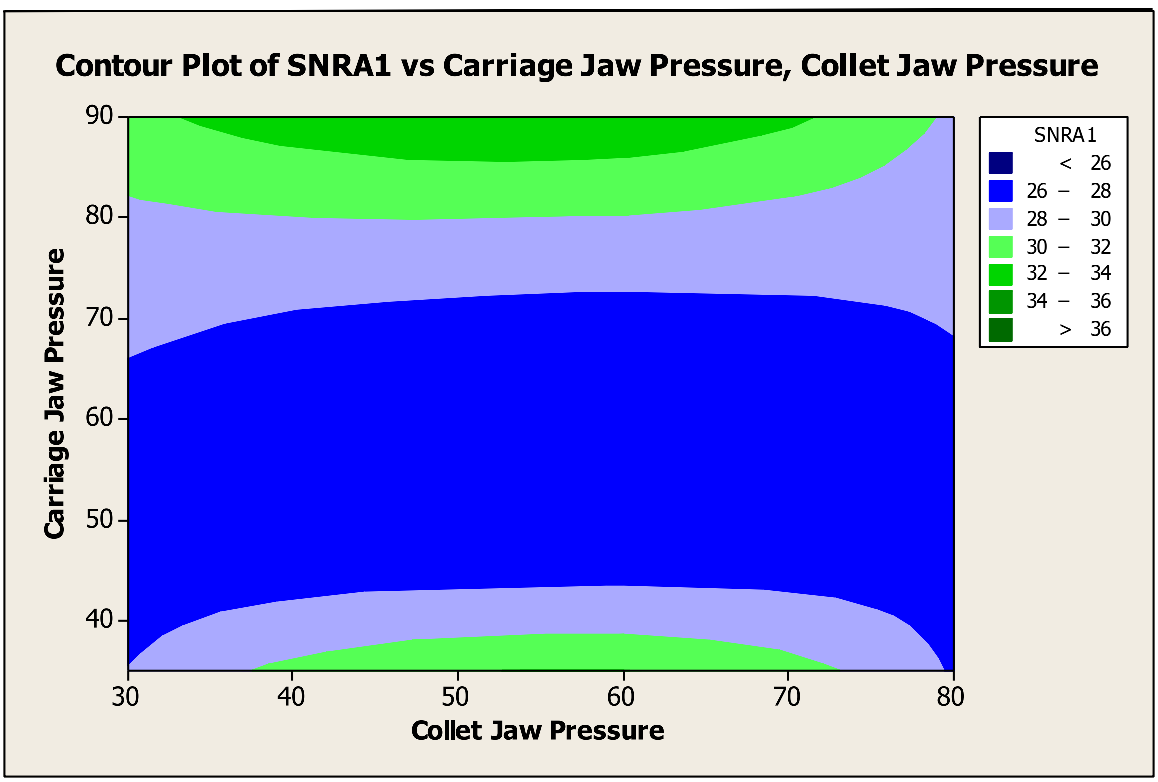
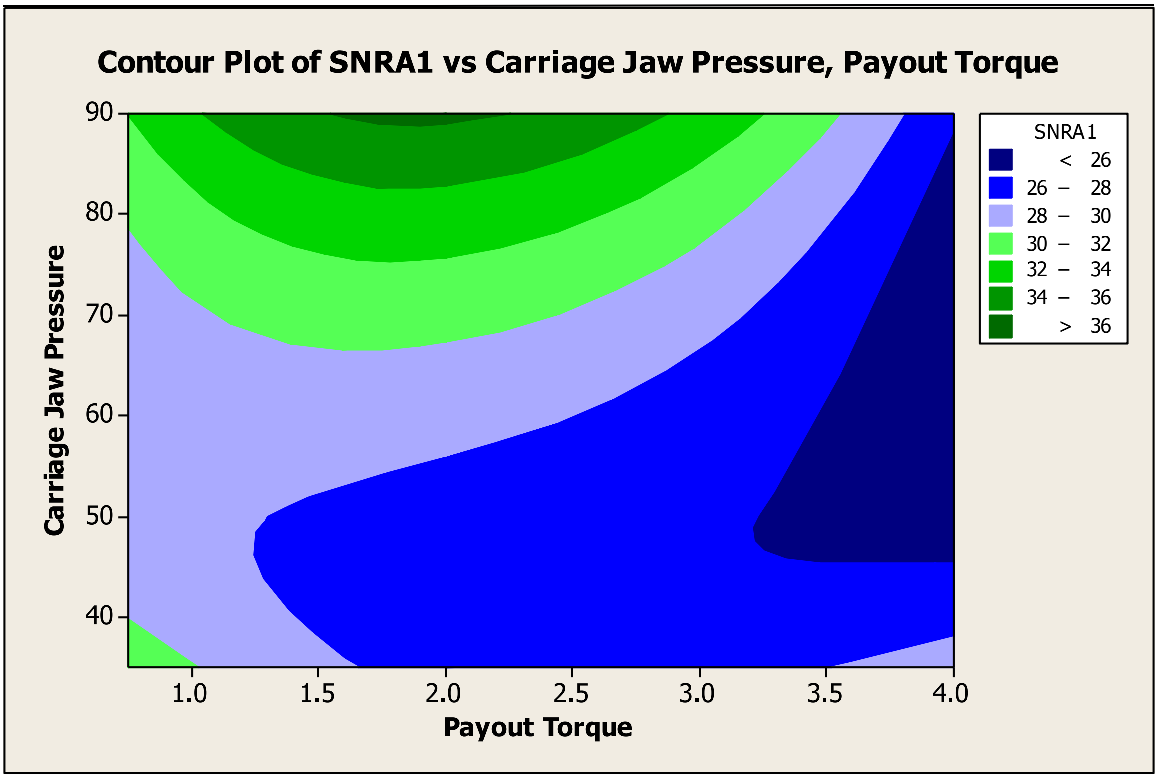
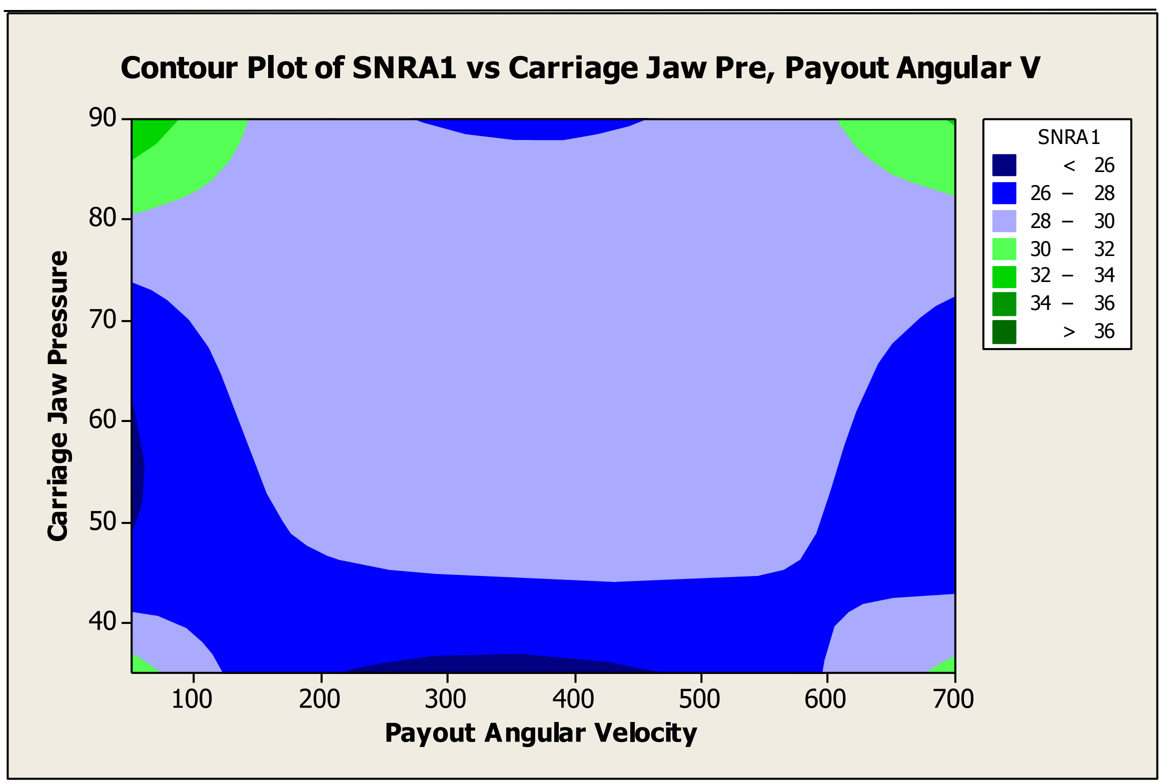
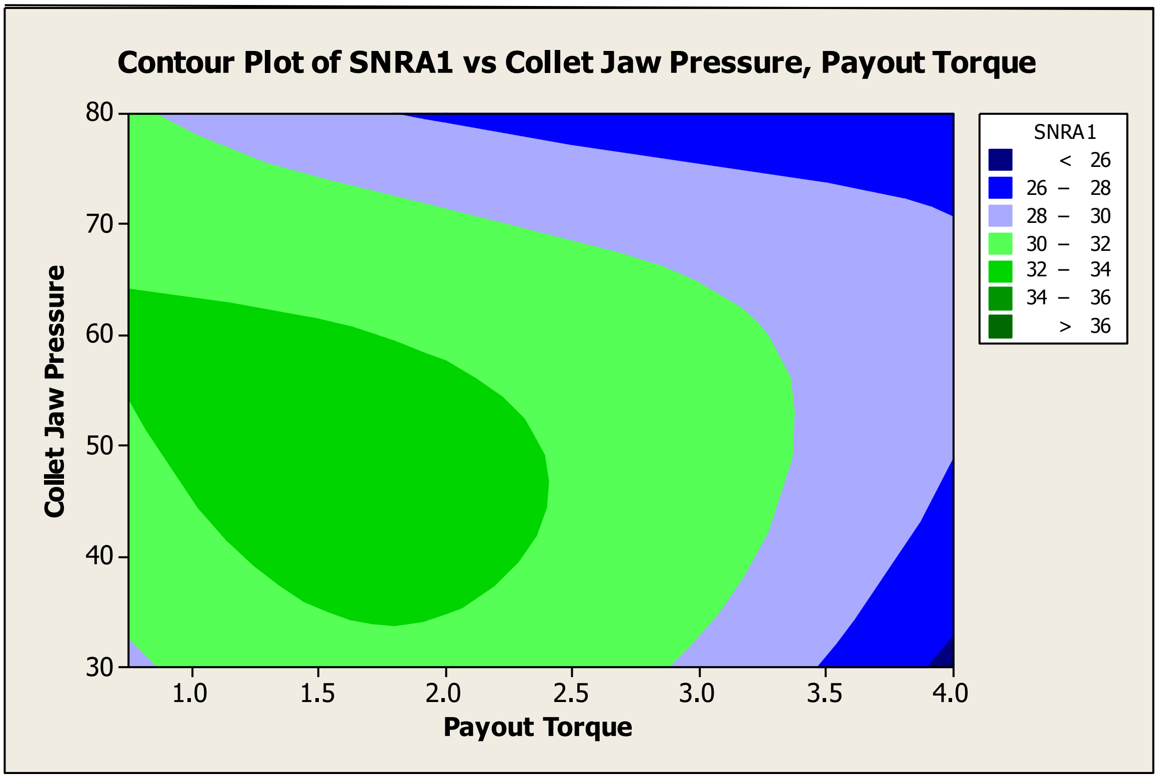
Carriage Deceleration
2500
2000
1500
1000
500
100
200
300
400
500
600
700
Payout Angular Velocity
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36

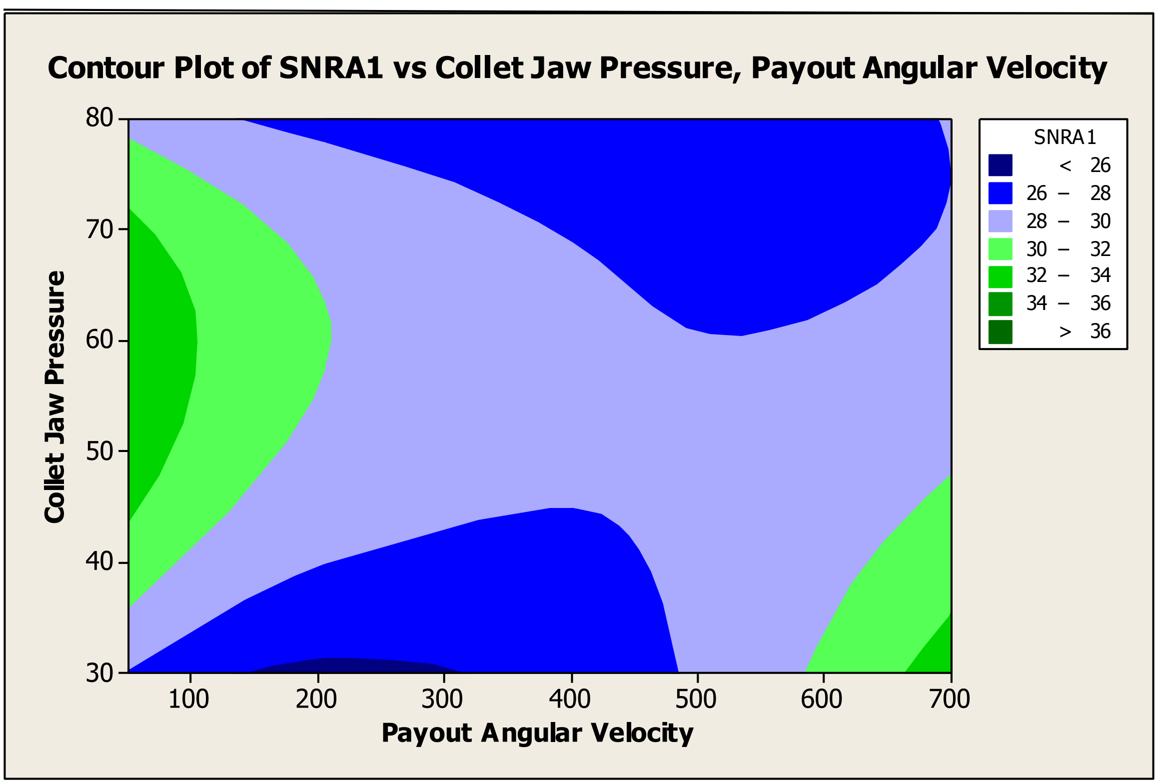

Contour Plot of SNRA1 vs Carriage Jaw Pressure, Collet Jaw Pressure
Carriage Jaw Pressure
90
80
70
60
50
40
30
40
50
60
70
80
Collet Jaw Pressure
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Jaw Pressure, Payout Torque
Carriage Jaw Pressure
90
80
70
60
50
40
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Payout Torque
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36


Contour Plot of SNRA1 vs Carriage Jaw Pre, Payout Angular V
Carriage Jaw Pressure
90
80
70
60
50
40
100
200
300
400
500
600
700
Payout Angular Velocity
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36



Contour Plot of SNRA1 vs Collet Jaw Pressure, Payout Torque
Collet Jaw Pressure
Payout Torque
30
40
50
60
70
80
1.0
1.5
2.0
2.5
3.0
3.5
4.0
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36



Contour Plot of SNRA1 vs Collet Jaw Pressure, Payout Angular Velocity
Collet Jaw Pressure
Payout Angular Velocity
30
40
50
60
70
80
100
200
300
400
500
600
700
SNRA1
< 26
26 – 28
28 – 30
30 – 32
32 – 34
34 – 36
> 36

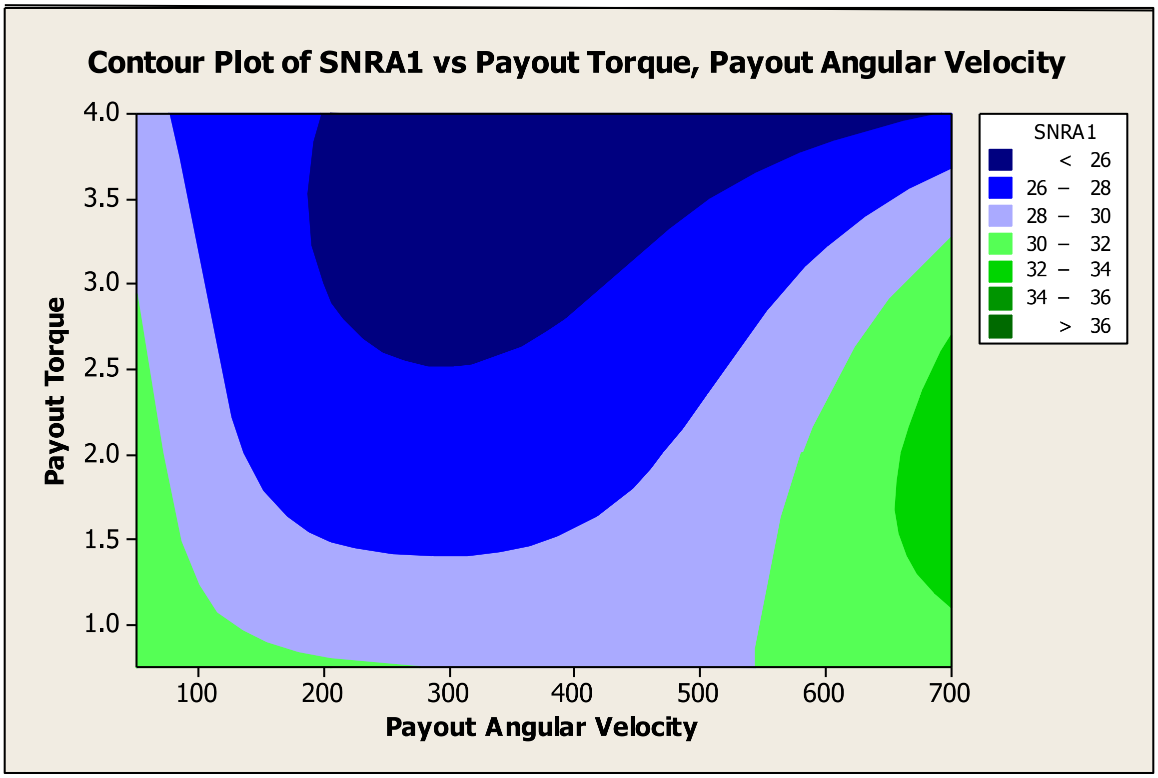


Figure 12: 28 Combinations of S/N Ratios Contour Plot

Minitab predicts that the optimum setting (the Stabilizer Oscillation at position 2, the Carriage Acceleration at position 3, the Carriage Velocity at position 2, the Carriage Deceleration at position 1, the Carriage Jaw Pressure at position 3, the Collet Jaw Pressure at position 2, the Payout Torque at position 1, the Payout Angular Velocity at position 1) to obtain the output length of the proximal ablation for nominal-the-best setting to be 20.6429 mm. The S/N ratio is 38.9548. The standard deviation is 0.0461780.

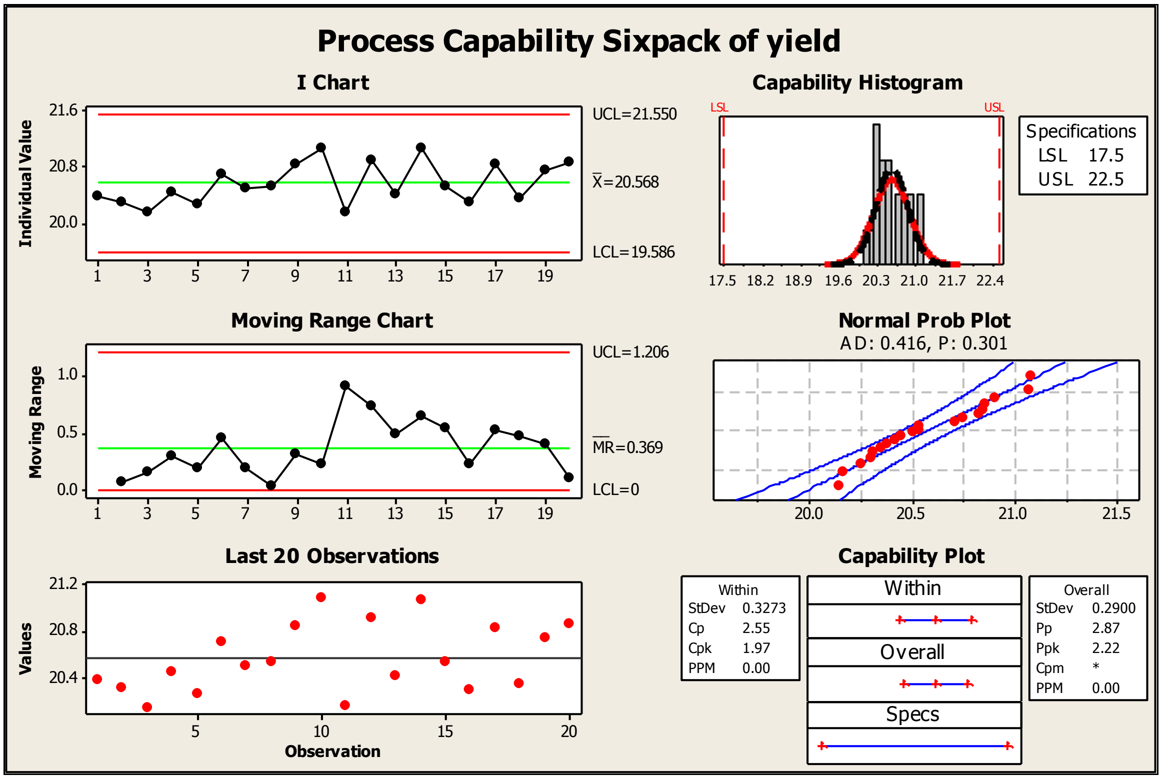


Figure 13: Process Capability Six-pack for Samples at Optima Setting

Figure 13 shows the samples at optima setting had a Ppk value of 2.22 compare with the performance baseline which only had a Ppk value of 0.96 had a 1.26 higher. Also, the mean of samples, 0.2900, are closed to the predicted result. Therefore, the results at optima setting would meet the goal of project objective.

Summary

This chapter detailed listed all collected data and analyzed. In the next chapter, the final result and conclusion of this project will be present.

Chapter V: Results, Conclusion, and Recommendations

Introduction

As a final chapter of this report, this chapter described the project overall results and conclusion.

Results

This project was a successful case study that implemented of Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) methodology to improve manufacture process. During this project, multiple strategies and tools have been used. According to results, all project questions could be answered.

1. What is the current state for the process at wire machine W08?

   Out of all dimensions the W08 wire Ablation machine had a lowest Ppk value of 0.96 for proximal ablation length.

2. What are the factors cause the yield loss?

   The most impression cause of yield loss was sensitivity setting for the laser micrometer system was tight than necessary condition. It direct caused the system failed good parts.

3. What changes will be made to the process during this study for improvement?

   There are some changes have been made during this study. First, the sensitivity setting for the laser micrometer system changed from 1x12 micron to 3x12 micron. Second, the machine profile setting changed to optima setting according to DOE results. It would reduce the variation of proximal ablation length and increase Ppk from below 1.0 to above.

4. What percentage of yield loss was reduced after the study was conducted? The yield loss would reduce from 10% to 2%.

Conclusion

In conclusion, this Six Sigma project was conducted for a process improvement in an engineered medical components company. This Six Sigma project was based on DMAIC methodology with various strategies and tools. During Design phase, the team created a project chart to define this project. At the measure phase of this project, the team collected current and p previous data and analyzed baseline performance of the process. It indicated the process had a lowest Ppk at 0.96 and a yield loss at 10%. When this project moved to analyze phase, brainstorming meeting was been held to find the root causes with some others experiments to verify. There were two studies conducted in improve phase. First one was the sensitivity study which compared different lot of samples under different sensitivity settings. The result showed that when sensitivity changes from 1x12 micron to 3x12 micron the yield loss would reduced from 10% to 2% which meet the first project objective. The other study was the biggest part in this project that conducting DOE in order to reduce the variation of proximal ablation length. By through Taguchi design, the result provided optima setting for each 8 factors to minimize noises. Then ANOVA tab indicated the scale of impact that each factor impact output. The results showed the lowest Ppk value of this product would be increased from 0.96 to 2.22 which meet the second project objective.

Recommendations

Although, an effort was made to improve the process by using Six Sigma methodology, the process are not perfect or ideal. The first pass yield of this production have not meet the six sigma standard and the cause are unknowing. The DOE conducted for length of proximal ablation also have not achieve to a fully satisfied level. There was a gap of standard deviation between prediction and verification. It means there is factor or factors cause the variation and it is unknowing. It is highly recommended that continually push process improvement through Six Sigma to achieve the goal that having 3.4 defects per million products produced.

References

Atkinson, P. (2014). DMAIC: A methodology for Lean Six Sigma business transformation. *Management Services, 58*(1), 12-17.

Eschenbach, T. G. (1995). *Engineering economy.* New York: Oxford University Press.

Gijo, E., & Scaria, J. (2014). Process improvement through Six Sigma with Beta correction: A case study of manufacturing company. *International Journal of Advanced Manufacturing Technology*, *71*(1-4), 717-730. doi:10.1007/s00170-013-5483-y

Khodaygan, S., & Movahhedy, M. (2014). *Functional process capability analysis in mechanical systems. International Journal of Advanced Manufacturing Technology, 73*(5-8), 899-912. doi:10.1007/s00170-014-5800-0

Kumaravadivel, A., & Natarajan, U. (2013). Application of Six-Sigma DMAIC methodology to sand-casting process with response surface methodology. International *Journal of Advanced Manufacturing Technology, 69*(5-8), 1403-1420.

Lazic, L., & Milinkovic, S. (2015). Reducing software defects removal cost via design of experiments using Taguchi approach. *Software Quality Joumal,* (2), 267.

Lem, S., Onghena, P., Verschaffel, L., & Van Dooren, W. (2013). The heuristic interpretation of box plots*. Learning and Instruction*, pp. 2622-2635. doi:10.1016/j.learninstruc.2013.01.001

Phadke, M., S. (1989). *Quality engineering using robust design.* New Jersey: Prentice Hall.

Appendix

Result of Keyence sensitivity comparison sample trial

Green light	Pass	Yellow light	failed proximal inspection	Red light	failed distal inspection
lot number	0722-2015	lot number	0723-2015	lot number	0724-2015
sensitivity	1x12	sensitivity	2x12	sensitivity	3x12
trial number	status	trial number	status	trial number	status
1	Green light	1	Green light	1	Green light
2	Green light	2	Green light	2	Green light
3	Green light	3	Green light	3	Green light
4	Red light	4	Green light	4	Green light
5	Green light	5	Green light	5	Green light
6	Green light	6	Green light	6	Green light
7	Green light	7	Green light	7	Green light
8	Green light	8	Green light	8	Green light
9	Green light	9	Green light	9	Green light
10	Green light	10	Green light	10	Green light
11	Green light	11	Green light	11	Green light
12	Green light	12	Green light	12	Green light
13	Green light	13	Green light	13	Green light
14	Green light	14	Green light	14	Green light
15	Green light	15	Green light	15	Green light

16	Green light	16	Green light	16	Green light
17	Green light	17	Green light	17	Green light
18	Green light	18	Green light	18	Green light
19	Green light	19	Green light	19	Green light
20	Green light	20	Green light	20	Green light
21	Green light	21	Green light	21	Green light
22	Green light	22	Green light	22	Green light
23	Green light	23	Green light	23	Green light
24	Green light	24	Green light	24	Green light
25	Green light	25	Green light	25	Green light
26	Green light	26	Green light	26	Green light
27	Green light	27	Green light	27	Green light
28	Green light	28	Green light	28	Green light
29	Green light	29	Green light	29	Green light
30	Green light	30	Green light	30	Green light
31	Green light	31	Green light	31	Green light
32	Green light	32	Green light	32	Green light
33	Green light	33	Green light	33	Green light
34	Green light	34	Green light	34	Green light
35	Green light	35	Green light	35	Green light
36	Green light	36	Green light	36	Green light

37	Green light	37	Green light	37	Green light
38	Green light	38	Green light	38	Green light
39	Green light	39	Green light	39	Green light
40	Green light	40	Green light	40	Green light
41	Green light	41	Green light	41	Red light
42	Yellow light	42	Green light	42	Red light
43	Green light	43	Green light	43	Green light
44	Green light	44	Green light	44	Green light
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46	Green light	46	Green light	46	Green light
47	Green light	47	Green light	47	Green light
48	Green light	48	Green light	48	Green light
49	Green light	49	Green light	49	Green light
50	Green light	50	Green light	50	Green light
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52	Green light	52	Green light	52	Green light
53	Green light	53	Green light	53	Green light
54	Green light	54	Green light	54	Green light
55	Red light	55	Green light	55	Green light
56	Green light	56	Green light	56	Green light
57	Green light	57	Green light	57	Green light

58	Green light	58	Green light	58	Green light
59	Green light	59	Green light	59	Green light
60	Red light	60	Green light	60	Green light
61	Green light	61	Green light	61	Green light
62	Green light	62	Green light	62	Green light
63	Green light	63	Green light	63	Green light
64	Green light	64	Green light	64	Green light
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72	Green light	72	Green light	72	Green light
73	Green light	73	Green light	73	Green light
74	Green light	74	Green light	74	Green light
75	Green light	75	Green light	75	Green light
76	Green light	76	Green light	76	Green light
77	Green light	77	Green light	77	Green light
78	Green light	78	Green light	78	Green light

79	Green light	79	Red light	79	Green light
80	Green light	80	Green light	80	Green light
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95	Green light	95	Green light	95	Green light
96	Green light	96	Green light	96	Green light
97	Green light	97	Green light	97	Green light
98	Green light	98	Green light	98	Green light
99	Green light	99	Green light	99	Green light

100	Green light	100	Green light	100	Green light
101	Green light	101	Green light	101	Green light
102	Green light	102	Green light	102	Green light
103	Green light	103	Green light	103	Green light
104	Green light	104	Green light	104	Green light
105	Green light	105	Green light	105	Green light
106	Yellow light	106	Green light	106	Green light
107	Green light	107	Green light	107	Green light
108	Green light	108	Green light	108	Red light
109	Green light	109	Green light	109	Green light
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132	Green light	132	Green light	132	Green light
133	Green light	133	Green light	133	Green light
134	Yellow light	134	Green light	134	Green light
135	Green light	135	Green light	135	Green light
136	Green light	136	Green light	136	Green light
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138	Green light	138	Green light	138	Green light
139	Green light	139	Green light	139	Green light
140	Green light	140	Green light	140	Green light
141	Green light	141	Yellow light	141	Green light

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149	Green light	149	Green light	149	Green light
150	Green light	150	Green light	150	Green light
151	Green light	151	Green light	151	Green light
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160	Green light	160	Green light	160	Green light
161	Yellow light	161	Green light	161	Green light
162	Green light	162	Green light	162	Green light

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170	Green light	170	Green light	170	Green light
171	Yellow light	171	Green light	171	Green light
172	Green light	172	Green light	172	Green light
173	Yellow light	173	Green light	173	Green light
174	Green light	174	Green light	174	Green light
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196	Green light	196	Green light	196	Green light
197	Green light	197	Green light	197	Green light
198	Yellow light	198	Green light	198	Green light
199	Green light	199	Green light	199	Green light
200	Green light	200	Green light	200	Green light
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202	Green light	202	Green light	202	Green light
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211	Green light	211	Green light	211	Green light
212	Green light	212	Green light	212	Green light
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221	Green light	221	Green light	221	Green light
222	Green light	222	Green light	222	Green light
223	Green light	223	Green light	223	Green light
224	Green light	224	Green light	224	Red light
225	Green light	225	Green light	225	Green light

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231	Green light	231	Red light	231	Green light
232	Green light	232	Green light	232	Green light
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250	Green light	250	Green light	250	Green light
Total	250	Total	250	Total	250